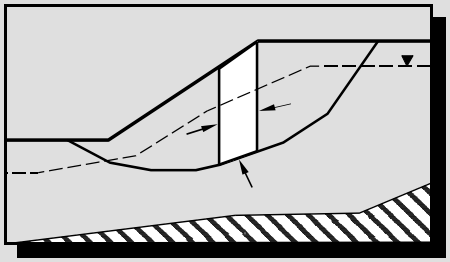
XSTABL©

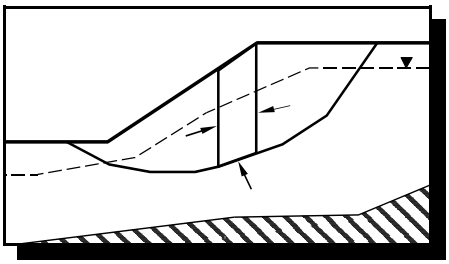
An Integrated Slope Stability Analysis Program for Personal Computers

Reference Manual

Version 5



Interactive Software Designs, Inc
Moscow, ID 83843, U.S.A.



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An Integrated Slope Stability Analysis Program for Personal Computers

Reference Manual

Version 5

prepared by

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for

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XSTABL

VERSION 5.2

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CHAPTER 1

1.0 INTRODUCTION

XSTABL is a fully integrated slope stability analysis program designed to operate on an IBM personal computer, or close compatible. It permits the engineer to develop the slope geometry interactively and perform the slope analysis from within a single program. The slope analysis portion of **XSTABL** uses a modified version of the popular STABL program, originally developed at Purdue University.

XSTABL performs a two dimensional limit equilibrium analysis to compute the factor of safety for a layered slope according to:

(a) General Limit Equilibrium (GLE) Method,

(b) Janbu's Generalized Procedure of Slices (GPS),

(c) Simplified Bishop,

(d) Simplified Janbu.

If the program is used to search for the most critical surface, only the simplified Bishop and Janbu methods are available for calculating the factor of safety. The program can be used to search for the most critical surface or the factor of safety may be determined for specific surfaces. **XSTABL**, version 5.0, is programmed to handle:

1. heterogenous soil systems with up to 20 soil units,
2. The strength of a soil unit may be defined using:
   (a) conventional, c-φ parameters,
   (b) undrained strengths as a function of vertical effective stress,
   (c) a nonlinear Mohr-Coulomb envelop.
3. Anisotropic soil strength properties,

4. Reinforced slopes,
5. Pore water pressures for effective stress analysis using:
   (a) phreatic and piezometric surfaces
   (b) pore pressure grid
   (c) R_u factor
   (d) constant pore water pressure
6. Pseudo-static earthquake loading,
7. Surcharge boundary loads,
8. Automatic generation and analysis of an unlimited number of circular, noncircular and block-shaped failure surfaces,
9. Analysis of right-facing slopes,
10. Both SI and English units.

1.1 Summary of Interactive Features of XSTABL

XSTABL is intended for use on an IBM-PC, or near compatible, suitably equipped for screen graphics. The program uses menus and data-tables to "guide" the potential user through the many options available for performing a slope stability analysis. The interactive features of **XSTABL** include:

1. Selection of options via intuitive, easy to understand menus,
2. Context sensitive help information,
3. All numeric data is entered through prompts into a table,
4. Error checking during data entry phase,
5. Slope geometry may be readily reviewed on-screen,
6. Previously entered data can be edited,
7. Single failure surfaces may be analyzed using several rigorous procedures that satisfy force and moment equilibrium,
8. Previously saved files can be edited and saved as "new" files,

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9. **XSTABL** files may be copied, deleted, printed, renamed or viewed *without* exiting the program,
10. Screen plots may be saved to disk in one of several different formats for later printing or inclusion within a document prepared with a wordprocessing or charting software.
11. High quality plots may be generated, using **XSTABL**, on several different types of output devices if the screen plots are saved in the default format.

It is expected that the approach offered by **XSTABL** will minimize potential errors and provide a more appropriate data preparation method for the less familiar user. The time expended in learning to use the program is expected to be nominal and users can be expected to generate input data files almost immediately.

1.2 General Information

The **XSTABL** Reference Manual is intended to provide information about the interactive features that allow the user to prepare data files and perform a slope stability analysis. The next six chapters of the Reference Manual provides details concerning the following topics:

1. **XSTABL** program components,
2. **XSTABL** menus and available options,
3. Data tables for establishing the slope geometry, and assigning soil properties and boundary loads,
4. Methods of analysis,
5. Slope stability analysis, including the creation and saving of screen plots,
6. Printing of hardcopy plots.

Further details about the limit equilibrium theory, search procedures and slice development are given in Appendix D, E and F.

This manual concentrates on the interactive features and is not intended to provide the necessary engineering background for slope stability analysis. If the user wishes to obtain more information concerning slope stability analysis, the following publications are recommended:

1. *Slope Stability and Stabilization Methods*, by Abramson, L. W., Lee, T. S., Sharma, S. and Boyce, G. M. (2002), John Wiley & Sons, Inc. (Pub.), 712 pages, ISBN 0-471-38493-3.

2. *The Stability of Slopes*, by E.N. Bromhead, Surrey University Press, Chapman and Hall, NY, 411 pages, ISBN 0-412-01061-5, 1992.

3. *Landslides: Investigation and Mitigation*, by A. Keith Turner and Robert L. Schuster (editors), Special Report 247, Transportation Research Board, National Academy of Sciences, Washington, D.C., ISBN 0-309-06151-2

Please note that the above list represents ***a very small*** portion of literature available on the subject of slope stability analysis.

1.3 Hardware Requirements

In order to use **XSTABL**, the user will require:

1. An IBM-PC, or near compatible, with a CD drive for installing the software. *Please contact I.S. Designs, Inc., if you do not have a CD drive and require the software on a diskette.*

   Execution of XSTABL will require at least 450,000 bytes of free RAM. The user may check the amount of RAM available by using the "MEM/C" command, as documented in the DOS manual.

2. An IBM compatible VGA, EGA or CGA graphics adaptor with an appropriate monitor,

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3. One of the following devices for hardcopy output:

   (a) A laser printer, e.g. Hewlett Packard LaserJet with at least 1 Mb of RAM, or

   (b) An IBM Graphics compatible, 9 or 24 pin, dot matrix printer, e.g. EPSON FX-85,

   (c) A HPGL compatible pen plotter, e.g. Hewlett Packard 7475A Plotter.

1.4 Connecting HP Plotters

XSTABL screen plots may be successfully plotted using HP plotter models: 7440A, 7470A, 7475A and 7550A connected to a personal computer. The cable should be connected to the PC with a DB 9 or DB 25 connector via the serial or asynchronous port. At the plotter, a DB 25 connector should be used to connect the cable to the computer/modem port. **XSTABL** uses the XON/XOFF protocol and thus only requires ***three*** connecting wires in accordance with Fig 1.1.

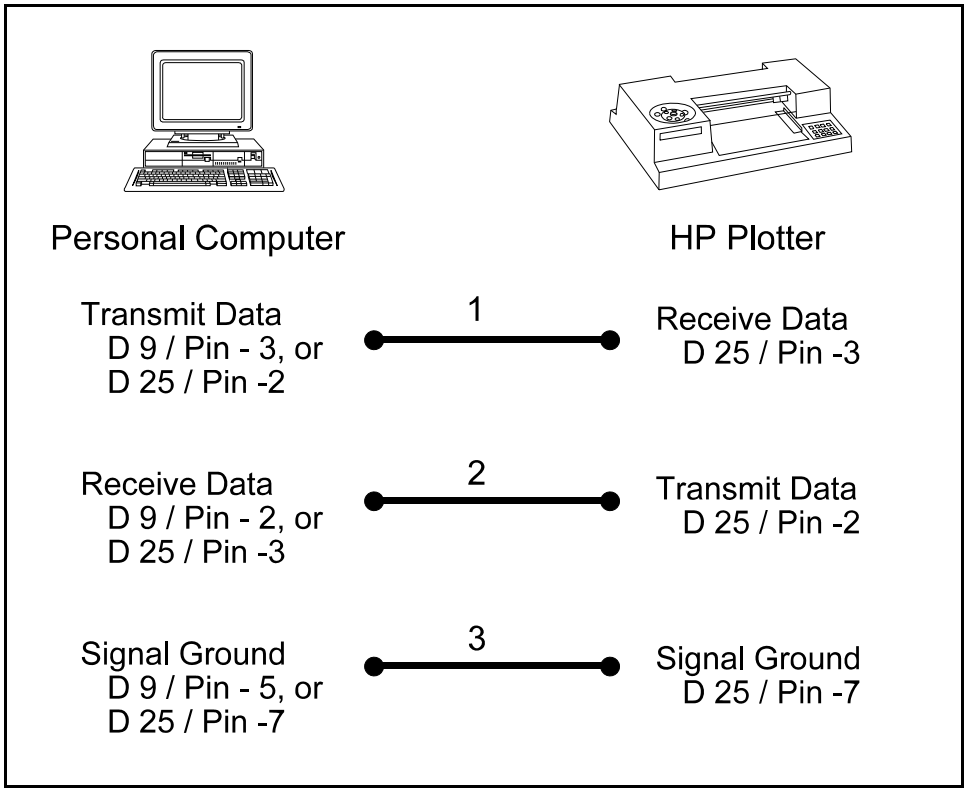

Fig. 1.1. Wire connections for PC - HP plotter cable

1.5 XSTABL INSTALLATION

The **XSTABL** programs and example data files may be installed from the installation CD. The software can be installed on a system running DOS or Windows. To install, insert the CD into the CD-drive and then follow these instructions:

WINDOWS 95, 98, Me, NT4, 2000 and XP installation

1. The installation should start automatically. If this option is disabled and the setup program does not start automatically, run the SETUP.EXE program on the CD by either(a) Locating the SETUP file on the CD using FILE EXPLORER, and then double clicking on it, or (b) going to "Start, Run" and then typing d:\setup.exe and pressing the "Enter" key (in this case "d" is the drive letter for the CD drive).
2. The setup will place the XSTABL icon on the desktop and create a folder in "Start, Programs" called "XSTABL Files".
3. Use the "Add-Remove" wizard in the control panel and install from the disk-drive.

NOTE: As XSTABL is a DOS program, you must follow strictly the “8.3" file naming convention for all files and directories. It is strongly recommended that you install XSTABL to the default directory: “C:\xstabl”.

DOS installation

To install XSTABL, copy all the files from the \XSTABL directory on the CD to your local hard-drive. These files should preferably be copied to the directory: "c:\xstabl". For information about setting the desktop icons, please consult the “Readme.txt” file on the CD.

1.6 XSTABL Components

Before using **XSTABL**, the user should ensure that files listed below, and in section 1.7, have been copied :

1. PACK.LST . . . . . summary of file descriptions
2. README . . . . . special "last-minute" notes or revisions to this Manual
3. DEMO.TXT . . . . . dialogue script for demonstration/tutorial
4. ERRORS.FIX . . . . . list of revisions made since release of version 5.1

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1.7 Files for using XSTABL

1. **XSTABL.EXE** . . . . . executable version of program
2. SETUP1.STB . . . . . file used during program startup
3. XSTABL.HLP . . . . . help screen information
4. XSTABL.ERR . . . . . XSTABL error descriptions
5. XSTABL.FN1 . . . . . font file for screen characters
6. XSTABL.FN2 . . . . . font file for hardcopy plots
7. XSTABL.ICO . . . . . XSTABL ICON for use with MS Windows
8. XSTABL.CFG . . . . . required XSTABL configuration file
9. XPLOT.EXE . . . . . executable program for hardcopy plots

The installation process will also copy the example input data files and the output (4 files) corresponding to an analysis using the file EX_1.IPT to the "EXAMPLES" subdirectory. These "extra" files may be deleted to conserve disk space.

Running XSTABL

Windows: Double click the XSTABL icon on the desktop, or select “XSTABL Files” from the START menu and choose “xstabl” from the sub-menu. If you want to run XSTABL in "FULL-SCREEN" mode, right click the XSTABL icon and set the screen property to full-screen.

DOS: XSTABL can be started by typing, XSTABL followed by pressing the ENTER key. Please note, you must be in the directory where XSTABL is installed!

Please note that the XSTABL software and documentation is copyrighted and may NOT be copied without permission. However, the user is permitted to make ONE archival backup copy of these files to guard against possible disk failure.

1.8 Supporting XSTABL files

File: **SETUP1.STB** -- contains initialization information that sets several parameters at the start of the **XSTABL** program. Also, the first line of this file may be modified to control the amount of information that is written into the output file following a slope analysis. A typical unmodified file will have the following form:

Line 1: 0 10 10 10
Line 2: 1.000 1.000 0.30 9.80
Line 3: (blank line)

Let the four values on the first line be labeled as **var-1**, **var-2**, **var-3** and **var-4**. Then the user is permitted to modify these according to the following:

var-1 = 0 (zero) for all cases, unless advised otherwise;

var-2 = value between 1 and 10, inclusive, for controlling the number of failure surface coordinates that will be listed in the output file following each slope analysis;

var-3 = value between 1 and 10, inclusive, for controlling the number of critical surfaces that will be *displayed on the screen* at the end of the slope analysis;

var-4 = value between 1 and 10, inclusive, for controlling the number of surfaces *plotted to the hardcopy file.*

Please note that the default for the number of surfaces is set at ten for all cases (i.e. var-2 = var-3 = var-4 = 10). These parameters may be changed directly by editing the SETUP1.STB file. Alternatively these may be changed from within **XSTABL** via the F5 key just before the start of the multiple search analysis.

The four values listed on the second line control the scaling and location of the hardcopy plot on paper. The first two values assign the scaling in the x and y direction of the plot. The last two numbers fix the origin of the plot on the basis of a global origin located in the right-hand corner of the printed 11 x 8.5 inch (landscape) page. The user can manipulate these values to scale the hardcopy plots, but must ensure that the aspect ratio of the vertical to horizontal axes is maintained at unity.

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Other Files:

The two files, **XSTABL.HLP** and **XSTABL.ERR**, are used by **XSTABL** to provide help and input data error information, respectively. Although the program can function without these files, on-line help information will not be available and error messages will not be written to the output file created during the slope stability analysis. However, error numbers will be written to the output file and the user can determine the corresponding message from the complete list of possible errors given in Appendix B.

1.9 Starting XSTABL

Depending on your operating system (i.e Window 9x, NT4, 2000, XP or DOS), XSTABL may be started according to the following instructions:

Windows: double click the XSTABL icon on the desktop, or select XSTABL from the START menu. If you want to run XSTABL in "FULL-SCREEN" mode, right click the XSTABL icon and set the screen property to full-screen.

DOS: XSTABL can be started by typing, XSTABL followed by pressing the ENTER key while you are in the directory occupied by the program's files. Please note that an error will be reported if the user attempts to execute **XSTABL** from a directory which does not have the SETUP1.STB file. Also, the program ***expects*** to access the files: XSTABL.HLP and XSTABL.ERR (i.e. the help and error files) from the current directory only.

In executing the program, **XSTABL** offers the user an opportunity to change three default parameters via a command line option. If the user executes the program by only typing "XSTABL", the following default options are invoked:

(a) Imperial units, i.e. pounds, psf, pcf and feet;

(b) Parallel printer port selected as LPT1;

(c) Serial port selected as COM1.

The parallel port is used for printing input and output files and for printing all slope analysis plots, except those sent to a plotter. In this case the plotter is assumed to be connected to the COM1 serial port. If the above default selection is not appropriate, the user may change any of these according to the command-line switches given below.

Alternative SI Units may be selected by executing the program by typing: "XSTABL -m" at the DOS prompt. In this case the program will startup with SI units represented by: kN, kPa (kilo Pascals), kN/m^3 and meters.

The Alternative Parallel Port LPT2 may be selected by starting the program by typing:
"XSTABL LPT2". This selection will send all parallel port output to the LPT2 port.

The Alternative Serial Port COM2 may be selected by starting the program by typing:
"XSTABL COM2". This selection will send the plotter output to the alternative serial port.

Any combination of the above three options is possible. For example by typing :
"XSTABL COM2 LPT2 -m" the user may invoke (1) COM2 as the serial port, (2) LPT2 as the default parallel printer port and (3) SI units.

1.10 Example Input and Output Files

Several data files are provided with the main programs, on the enclosed disk, for evaluating the **XSTABL** software. These files are based on the slope geometry described in Appendix A of this manual. The output files, for example EX_1.IPT, are also included for the convenience of the user and to check for proper operation of **XSTABL** on your computer. A complete description of these example files is summarized in the disk file: PACK.LST.

1.11 XSTABL Tutorial

A dialogue script for a tutorial that demonstrates some of the unique features of **XSTABL** is included in the file: DEMO.TXT, which may be accessed from the “Xstabl Files” menu. The user is encouraged to print this file, and follow the suggested instructions. This tutorial will familiarize users with the editing features, special commands and other data tables that are used to assemble a data file for slope stability analysis.

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1.12 ANSI.SYS Device Driver

The **XSTABL** program has been designed to access the video hardware directly, thus minimizing the response time between keyboard entry and subsequent actions. However if the **ANSI.SYS** device driver is loaded, it "filters" the data before it is written to the screen. Thus in order to maximize the speed of **XSTABL**, the use of the ANSI.SYS device driver is not recommended as it tends to slow the response time for data written to screen.

The user may check to see if the ANSI.SYS driver is loaded by examining the CONFIG.SYS file in the root directory. A line of the general form :

DEVICE=ANSI.SYS

will indicate that the device driver is loaded at the start of every session. The user must then choose to either load or omit the ANSI.SYS device driver.

1.13 Loading and Execution Errors

It is possible that an "unexplainable" error may occur during the loading and execution phase of the program. If such an error occurs, please check your data thoroughly. If your data appears to be correct and the error condition persists, please contact:

Dr. Sunil Sharma,
Interactive Software Designs, Inc.,
953 N. Cleveland,
Moscow, ID 83843.
Email: **ssharma@uidaho.edu**
Web: **www.xstabl.com**

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CHAPTER 2

2.0 MENU STRUCTURE OF XSTABL

XSTABL consists of two interactive, but separate, portions: (1) the data preparation interface and (2) the slope stability analysis program. The general structure of the "interface" portion of the program consists of three screen menus:

(a) **MAIN** menu,

(b) **PREPARE SLOPE DATA** menu,

(c) **SLOPE ANALYSIS** menu.

This chapter will discuss the five options available from the main menu. If the user selects the "Prepare Slope Data" option, menu (b) is presented to the user, making available 19 options for entering numeric data to create the input file for the slope stability analysis. The third menu prompts the user for the names of the input and output files for the slope stability analysis.

Fig. 2.1 illustrates the overall structure of the interface and shows the relationships between the different menus. In the "Prepare Slope Data" menu, drop-down menus are offered to the user to quickly select the many available options. These options are illustrated in Fig. 2.1, next to their individual, unique categories:

1. PROFILE,
2. SOIL,
3. WATER,
4. ANALYSIS,
5. LOADS/LIMITS.

Upon highlighting and then selecting any one of the options, the user is presented a "Table" for entering numerical data. These tables are described in greater detail in the next chapter.

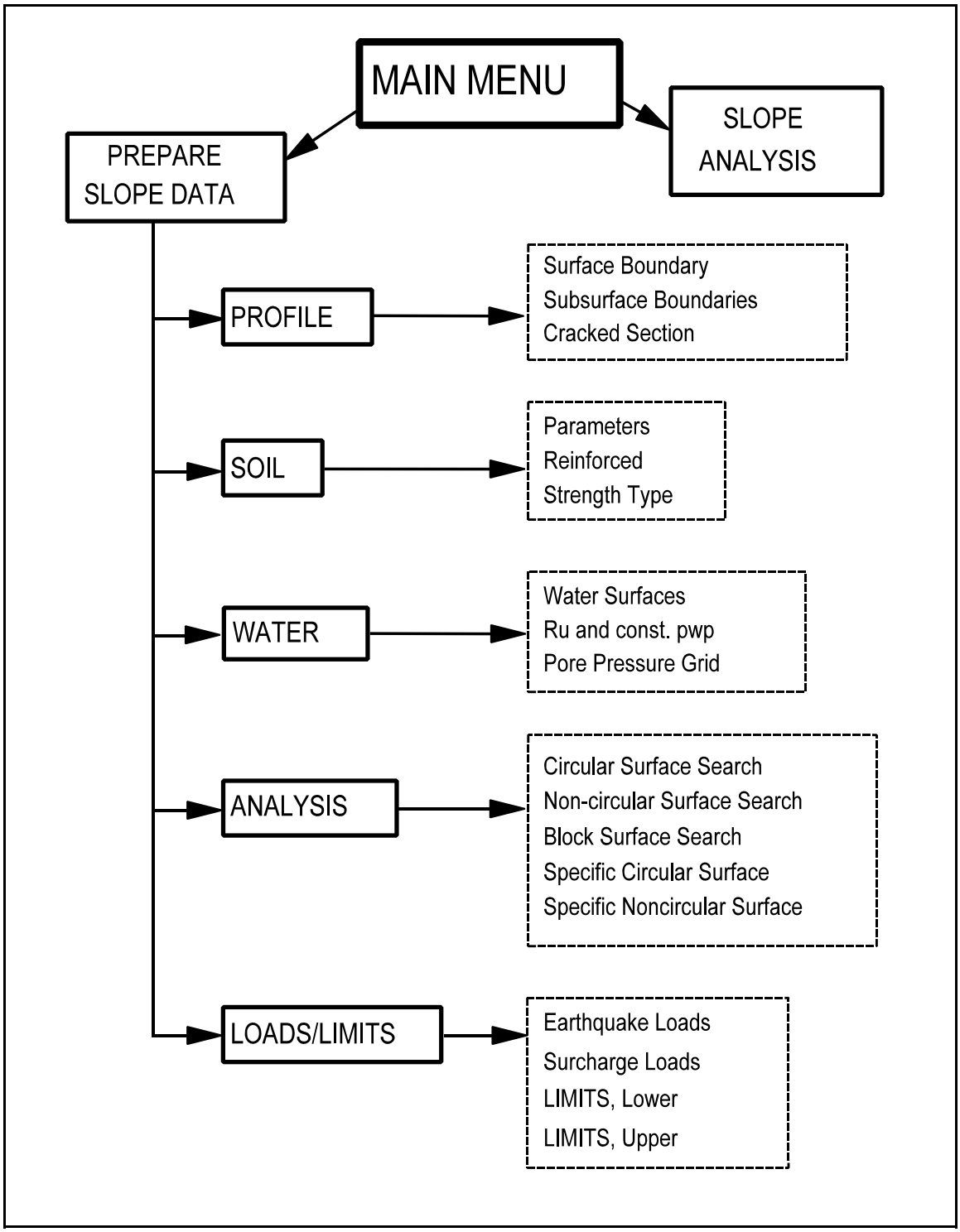

Fig. 2.1. Hierarchial structure of **XSTABL** menus and options

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2.1 Main Menu

When the user first types "XSTABL" to load the program at the DOS prompt, the copyright notice will be followed by the "Main Menu" shown in Fig. 2.2, below.

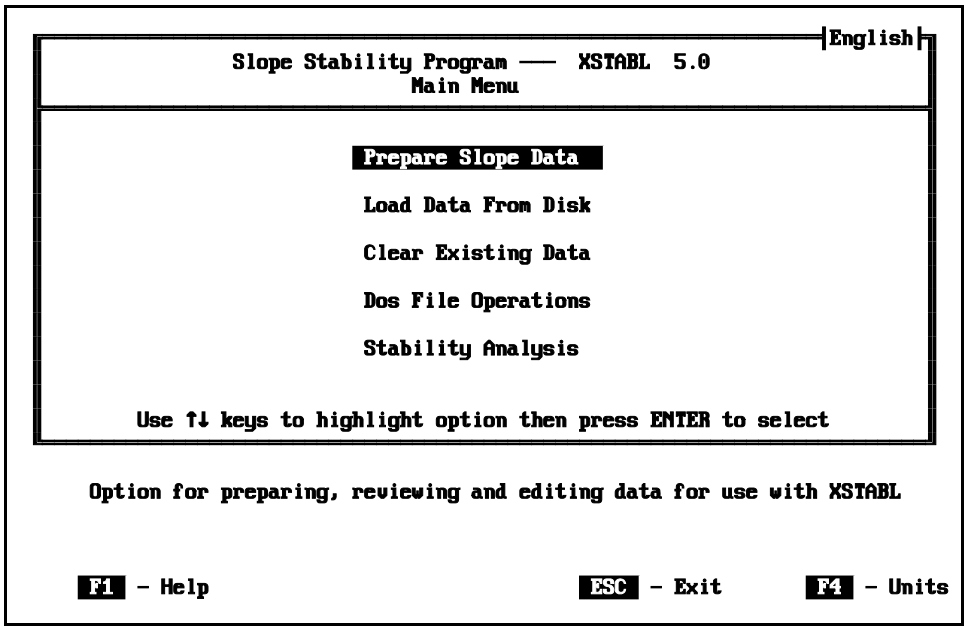
English
Slope Stability Program —— XSTABL 5.0
Main Menu
Prepare Slope Data
Load Data From Disk
Clear Existing Data
Dos File Operations
Stability Analysis
Use ↑↓ keys to highlight option then press ENTER to select
Option for preparing, reviewing and editing data for use with XSTABL
F1 - Help
ESC - Exit
F4 - Units

Fig. 2.2. Main Menu of **XSTABL**

All menus have been constructed to provide similar information at identical locations on the screen. This information consists of:

1. Title of menu on second line,
2. Filename (if data file has been loaded) is given in the middle of the lower bounding line of the menu, shown as: A:\EX_2 in Fig. 2.4,
3. A one-line description about the currently highlighted option is given below the lower bounding line,
4. The currently selected unit-system (English or SI) is displayed in the upper right corner,
5. Special commands associated with the "**F** keys" and **ESC** key are shown along the lower part of the screen.

2.2 Special Commands

The user may invoke special commands by pressing one of the "**F** keys" or the **ESC** key. The keys associated with the available commands are shown in the lower portion of the screen (for example, see Fig. 2.3). A summary of these commands is presented below:

F1 -- provides context-sensitive help information,

F2 -- displays a plot of the current slope geometry,

F3 -- offered during prompt for filename, allows user to access a directory listing to ease file selection,

F4 -- used to toggle between English and Metric (SI) units

F5 -- used to control number of failure surfaces displayed (file SETUP1.XTB)

ESC - allows user to exit current task, i.e. from a menu or data table, or a file or directory name prompt.

Some of these special commands are also available during entry of data into the tables. If an expected command is NOT shown, it implies that it is not available at that particular stage.

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2.3 XSTABL Filename Convention

In using **XSTABL**, the user is prompted for names of input data or output files. These prompts are all similar to the one shown in Fig. 2.3, below.

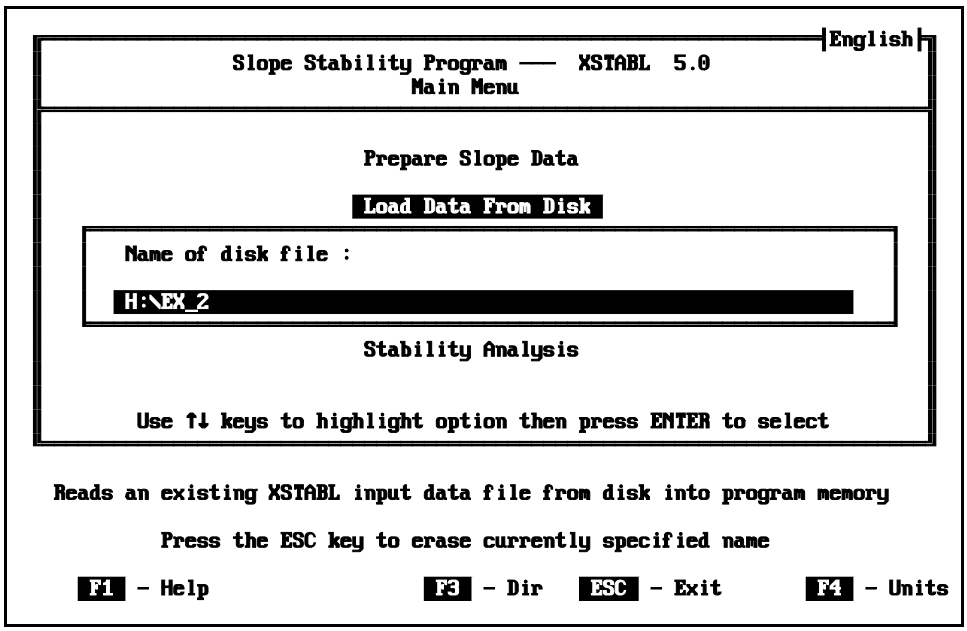
English
Slope Stability Program — XSTABL 5.0
Main Menu
Prepare Slope Data
Load Data From Disk
Name of disk file :
H:\EX_2
Stability Analysis
Use ↑↓ keys to highlight option then press ENTER to select
Reads an existing XSTABL input data file from disk into program memory
Press the ESC key to erase currently specified name
F1 - Help
F3 - Dir
ESC - Exit
F4 - Units

Fig. 2.3. Prompt for name of file to be loaded into **XSTABL**

The name may be entered directly at this point, or by pressing the **F3** key, the user may access any existing directory to view a list of files for possible selection. Please note that if the directory option is used, **XSTABL** will only display the files that have the relevant extension, i.e. *.IPT files for input filenames, or *.OPT files for output filenames.

The user is only permitted to enter the name of the file and an extension is added according to the following convention :

(a) filename.**IPT** ———— input data files

(b) filename.**OPT** ———— output data files

Additionally, during the slope analysis the user may elect to save the screen plots for later hardcopy printing. For such cases the plot files are automatically given the same name as that of the output file but with the following extension :

(a) output.**GP1** —— plot of slope geometry

(b) output.**GP2** —— plot of ALL surfaces generated during the analysis

(c) output.**GP3** —— plot of the most critical surfaces (or single, user specified surface)

(d) output.**GP4** —— plot generated for the rigorous solution of a single specified surface.

If the user selects the alternative WPG (WordPerfect graphics) or HPGL format, the same file will have the extensions *.WP? (WPG) and *.HP? (HPGL).

After loading an **XSTABL** file (a:\EX_2) and returning to the main menu, the filename will be displayed at the base of the menu as shown in Fig. 2.4, below.

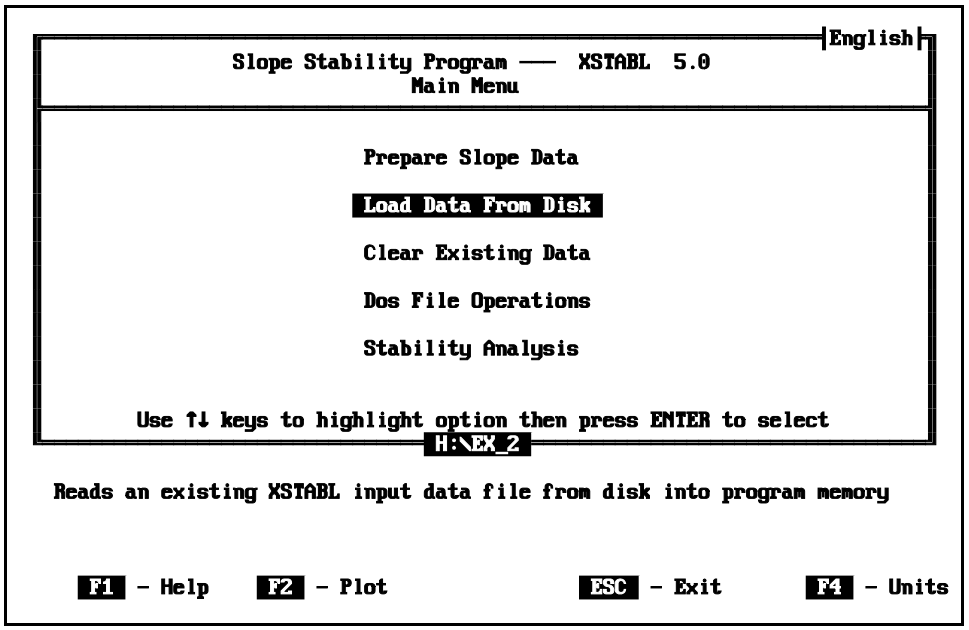
English
Slope Stability Program —— XSTABL 5.0
Main Menu
Prepare Slope Data
Load Data From Disk
Clear Existing Data
Dos File Operations
Stability Analysis
Use ↑↓ keys to highlight option then press ENTER to select
H:\EX_2
Reads an existing XSTABL input data file from disk into program memory
F1 - Help
F2 - Plot
ESC - Exit
F4 - Units

Fig. 2.4. Main Menu displaying name of loaded **XSTABL** file

With a file loaded, the **F2** index key will be displayed in the lower part of the screen. By pressing the **F2** key the user may readily view the slope geometry to verify that the correct file is loaded or

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to review the data. Once a file is loaded, it can be viewed, edited and subsequently saved for a slope analysis.

2.4 Other Filename Formats

There are four other filenames formats that are used by **XSTABL** to facilitate the data preparation and analysis phases. The format are:

***.PWG** This extension is reserved for an ASCII datafile that contains pore pressure data for a grid (i.e. x, y, u) that is to be imported into **XSTABL**. This filename extension allows the user to perform a directory search for selecting the file.

***.NLM** This extension is reserved for an ASCII data file that contains the effective normal stress and shear strength data (i.e. σ, τ pairs) used to describe a nonlinear Mohr-Coulomb envelop. This file is imported into **XSTABL** for assigning the NLMC properties of a soil unit. This filename extension allows the user to perform a directory search for selecting the file.

***.GLE** A file with this extension can be created by **XSTABL** or the user for assigning an interslice force angle distribution for use with the rigorous GLE method of analysis. Such a file allows the use of similar functions for different studies without having to re-type the data for each analysis. This filename extension allows the user to perform a directory search for selecting the appropriate file.

***.RJB** A file with this extension can be created by **XSTABL** or the user for assigning the location of the thrust line for use with the rigorous Janbu GPS method of analysis. Such a file allows the use of similar functions for different studies without having to re-type the data for each analysis. This filename extension allows the user to perform a directory search for selecting the appropriate file.

2.5 Prepare Slope Data Menu

If the user presses the **ENTER** key while the first option: "Prepare Slope Data" is highlighted, the screen will clear and the menu shown in Fig. 2.5 will be presented to the user.

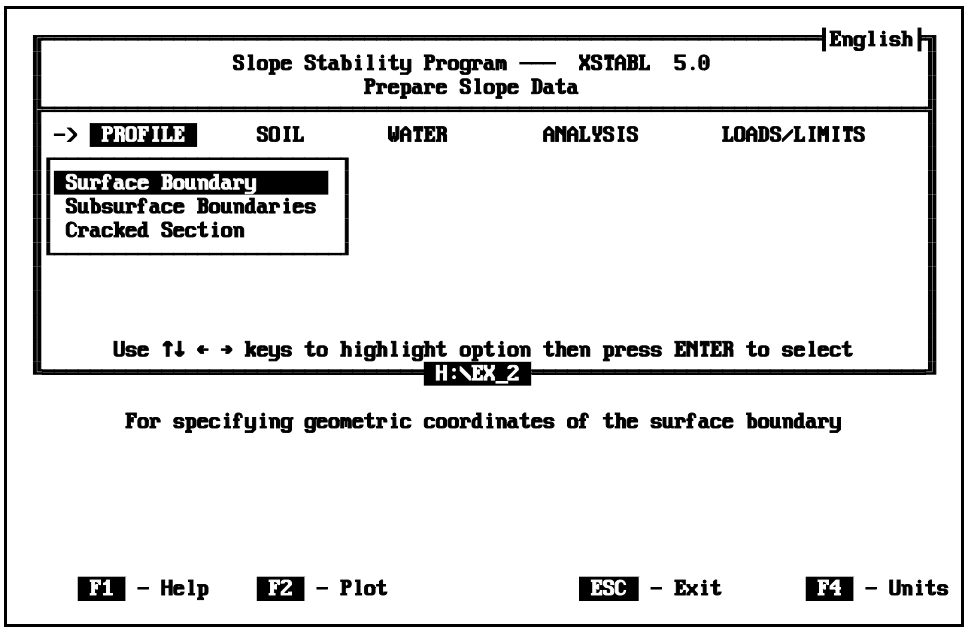

Fig. 2.5. Prepare Slope Data Menu -- PROFILE

This is a typical "drop-down" menu where the user can move to different categories using the LEFT/RIGHT cursor keys, or to different options using the UP/DOWN cursor keys. Initially, the first category, PROFILE, is selected where the two available options are:
(1) Surface Boundary, (2) Subsurface Boundaries, and (3) Cracked Section.

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If the right-cursor key is pressed, a new menu appears under the "SOIL" category (see Fig. 2.6) and presents two options under this category.

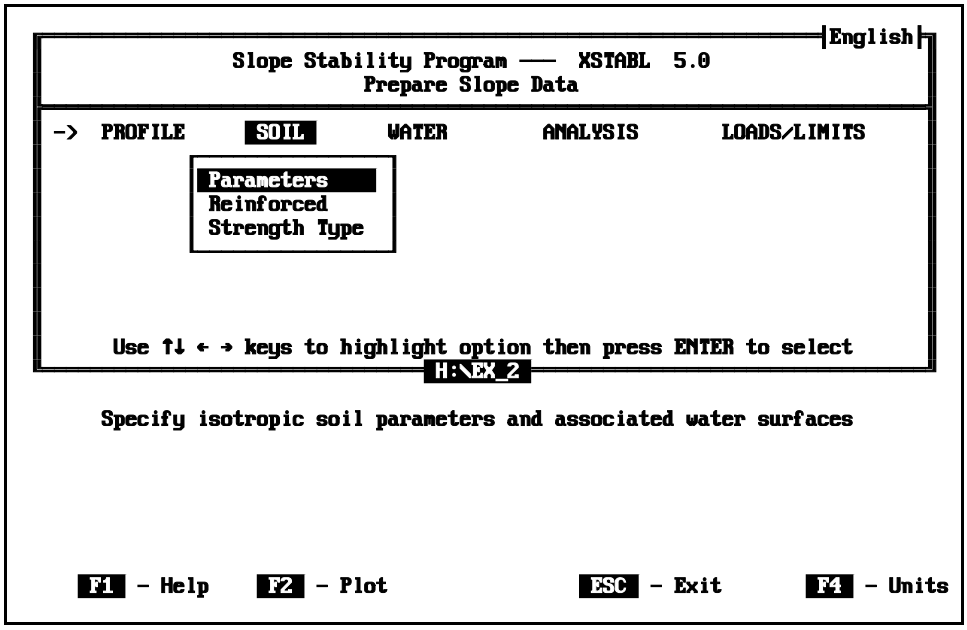

Fig. 2.6. Prepare Slope Data Menu -- SOIL

If the right cursor is pressed again, other options are made available for entering the slope data. The user may consult Fig. 2.1 for a summary of available options for each category.

From the "Prepare Slope Data" menu, the user will enter all data for developing the geometry of the slope, assigning soil strengths, defining water surfaces, selecting the appropriate analytical method and for assigning external loads and special limiting boundaries.

Exit from Prepare Slope Data Menu

The user may exit from the "Prepare Slope Data" menu by pressing the **ESC** key. The program will then prompt the user for the name of a file where the currently prepared slope data may be saved for later use. **XSTABL** will offer the "last" file name specified as a default, but the user is free to make appropriate changes so that each data set has a unique identifier. After entering the name of the file, the user is next prompted for a "project name". This name is used as a title for the plots, and in the output files.

If the user selects the name of an existing file, **XSTABL** will warn the user about the existence of a file with the same name. The user may then choose to overwrite the existing file or elect to respond with a different (unique) filename. An example of these prompts is shown in Fig. 2.7, below.

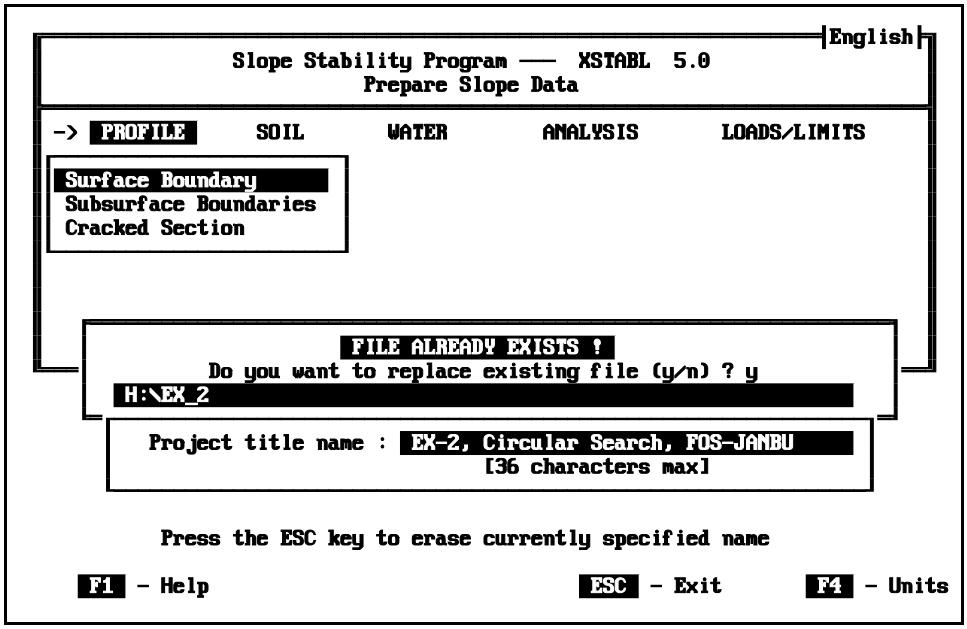

Fig. 2.7. Filename and project name prompt for saving slope data to a permanent diskfile

This figure illustrates the state of the screen after successfully entering the filename (i.e. G:\EX_2) and completing the "project name" prompt. If you do not wish to save the data to a permanent file on disk, pressing the **ESC** key twice will return the user to the main menu.

2.6 Load Data from Disk

Once **XSTABL** input files (*.IPT) have been created and saved, they may be re-loaded into the program for further review or editing. This feature may also be used to view slope geometries of files before performing a slope stability analysis.

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2.7 Clear Existing Data

This option is available in **XSTABL** for clearing data before developing a new slope profile for analysis. Any data that currently exists in the program memory (RAM) will be erased and will be lost permanently. This will not affect any data that has been permanently saved to a disk file. The final outcome is similar to exiting **XSTABL** and then restarting the program. Thus the user should make sure that useful data is saved prior to selecting this option. Once this option is invoked, the user may start developing a new input data file.

2.8 DOS File Operations

This option allows the user to perform certain tasks that manipulate **XSTABL** files without having to exit to DOS. When this option is selected, the user is prompted for the name of a directory. At this prompt the user should type the name of the working directory where the relevant **XSTABL** files are located. Please note that if a directory has been previously specified, **XSTABL** will offer this same name as a default.

Upon entering the name of a valid, existing directory, the screen clears and a listing of up to 200 **XSTABL** files (selected according to the unique filename extensions) will be displayed. Fig. 2.8 shows a typical listing for files located on drive: A, as indicated by the directory path on the first line. From this figure, the user may get additional information concerning: (1) the total number of **XSTABL** files, and (2) amount of remaining disk space in bytes.

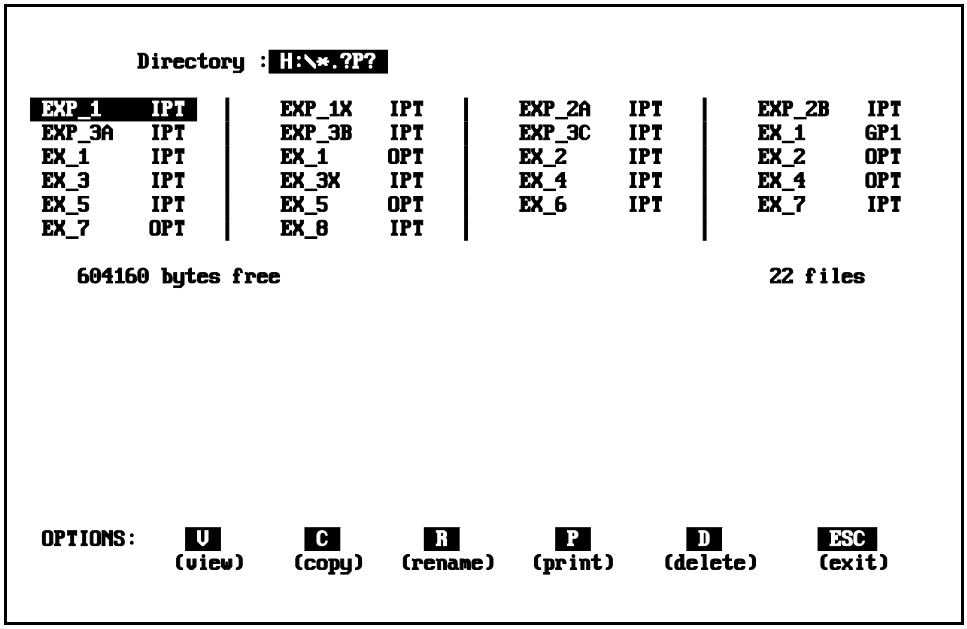

Fig. 2.8. List of **XSTABL** files on drive "H" -- DOS File Operations

Please note that if the directory listing indicates that zero files exist, it implies:

(a) there are no **XSTABL** files in the requested directory, or

(b) the directory does not exist.

In most cases, an incorrectly entered directory path name is the cause for zero files being reported by this option.

The available file operation commands are given in the lower part of the screen and are chosen by pressing the key corresponding to the first character of the command name. For example, pressing "v" (or "V") selects the "View" command, pressing "c" (or "C") for "Copy", etc. Each of these commands apply to the currently highlighted filename only.

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These commands are discussed below:

View — used to ***browse*** through **XSTABL** input or output files or to view plots saved in the *.GP? format. If the user attempts to browse through a *.WP? or *.HP? plot file, a warning message will be given, followed by a cancellation of the command.

In using the "view" option, the user should pay attention to the top line of the screen where the commands for moving within the file are summarized.

Copy — used to copy files. Only the filename is required as the same extension will be affixed to the new filename. Files may be copied to other directories or drives.

Rename — may be used to change the name of an existing file. Please note that the renaming will change the name of a file in the specified directory only. You cannot "rename" a file to another directory or drive. With this limitation, **XSTABL** will prompt the user for a filename of up to eight characters.

Print — used to print **XSTABL** input or output files to the default PRN device. If a "Plot" file is selected for printing, the user will be prompted for information concerning the desired plot resolution and type of output device, as shown in Fig. 2.9. If you do NOT want to continue, press **ESC** to cancel the print command.

Delete — may be used to delete the filename that is currently highlighted. When this command is used, the user will be asked to confirm the deletion as **the deleted file cannot be recovered later.**

ESC — used to **exit** from "DOS FILE OPERATIONS" to the Main Menu.

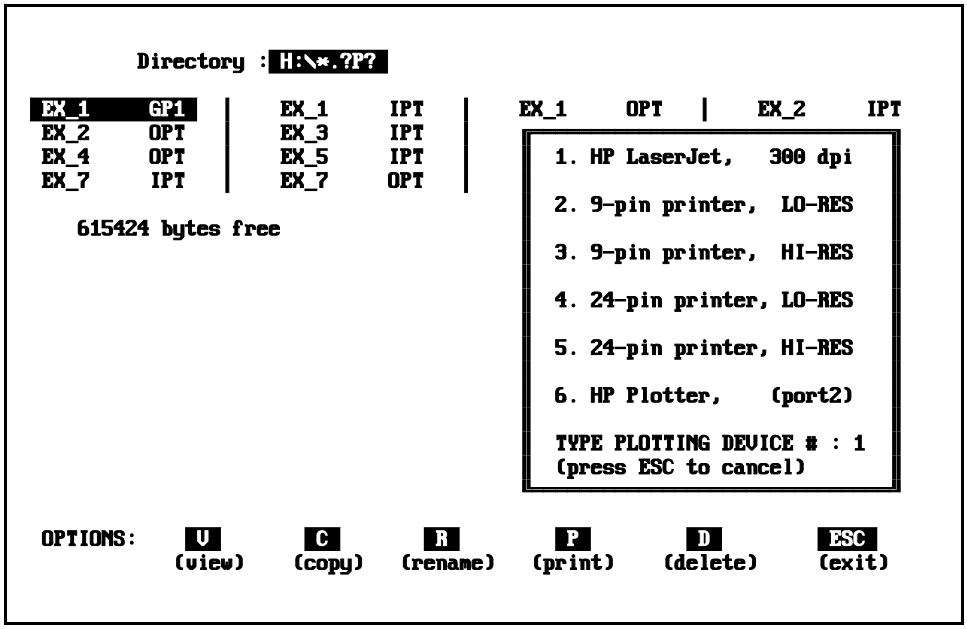

Fig. 2.9. Options for printing graphical format files (*.GP?) directly from **XSTABL**

Format of Input Data Files

The input data file (*.IPT) viewed using the "**V**iew" option is assembled with a fixed format that is compatible with the requirements for the slope stability analysis portion of **XSTABL**. This format is similar to requirements that were originally specified in the STABL User Manual and essentially consists of unique keywords followed by a block of numeric data. For the convenience of the user, this format requirement is included in Appendix B, as an aid to interpreting the input data files.

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2.9 Slope Analysis Menu

Fig. 2.10 shows the third menu that is presented to the user when the "Stability Analysis" option is selected from the main menu. This is a relatively simple menu structure, and is mainly used to prompt the user for the names of the input and output files associated with the stability analysis.

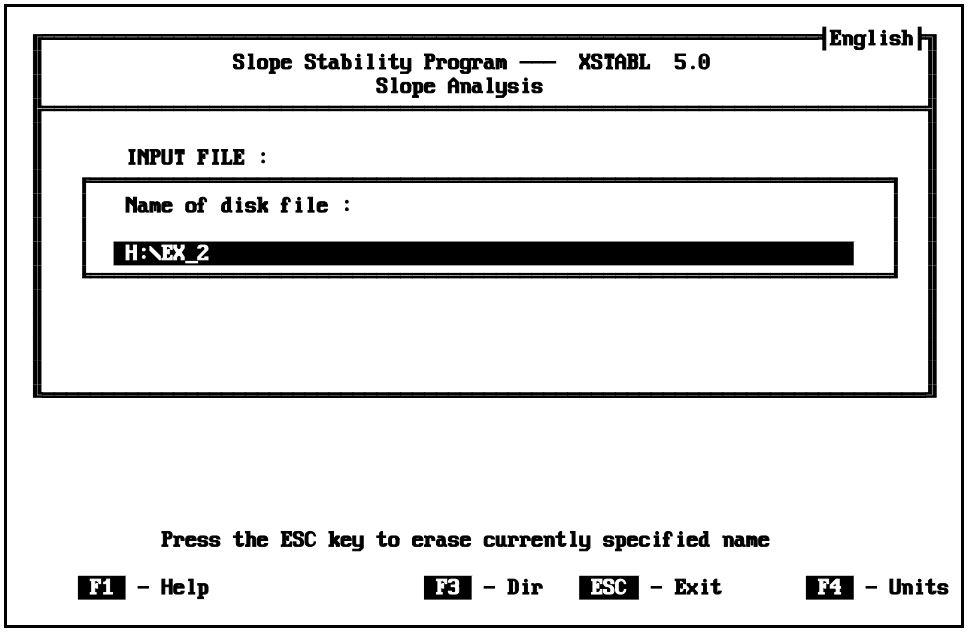

Fig. 2.10. Executing STABILITY ANALYSIS Menu

The user may access any existing directory to select an input data file by pressing the **F3** key. If a directory is accessed, the user may also view existing input or output files. This option is useful to ensure that the correct input file is, indeed, selected for the slope analysis. The output filename will default to the same name provided for the input file. However, the currently highlighted filename may be edited (or replaced) if the user wishes to use a different name. A later chapter discusses the slope analysis operations in greater detail, including the screen graphics and hardcopy plots.

2.10 Help Screens (F1)

Context-sensitive help is available by pressing the **F1** key from the menus and tables used in **XSTABL**. This "help" consists of up to three screens of information for each topic and are intended to provide useful details concerning the current task. For example, if the user presses the **F1**-key while viewing the Main Menu, the help screen shown in Fig. 2.11 will be displayed.

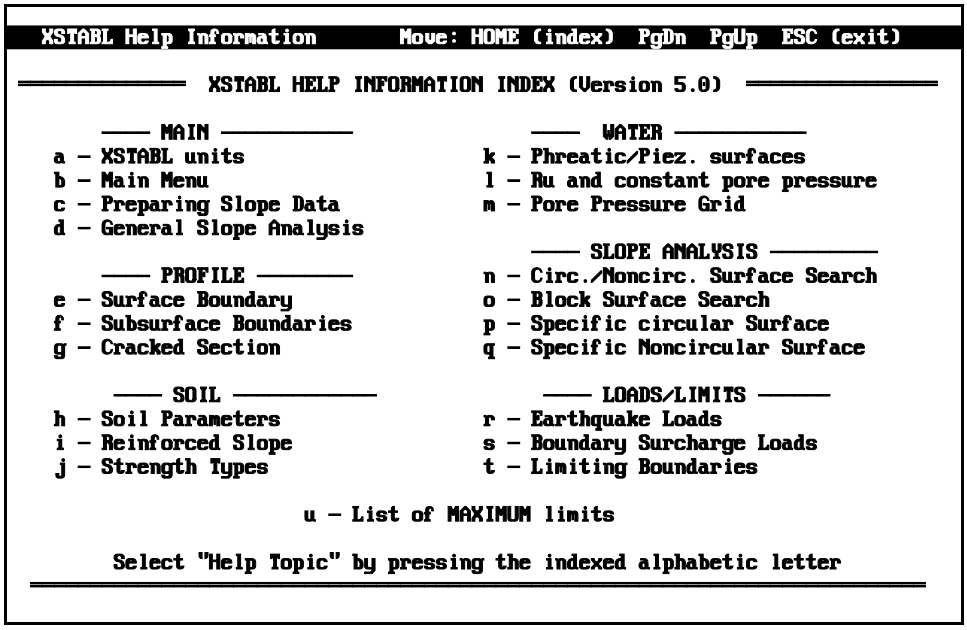
XSTABL Help Information Move: HOME (index) PgDn PgUp ESC (exit)
XSTABL HELP INFORMATION INDEX (Version 5.0)
MAIN
a - XSTABL units
b - Main Menu
c - Preparing Slope Data
d - General Slope Analysis
PROFILE
e - Surface Boundary
f - Subsurface Boundaries
g - Cracked Section
SOIL
h - Soil Parameters
i - Reinforced Slope
j - Strength Types
WATER
k - Phreatic/Piez. surfaces
l - Ru and constant pore pressure
m - Pore Pressure Grid
SLOPE ANALYSIS
n - Circ./Noncirc. Surface Search
o - Block Surface Search
p - Specific circular Surface
q - Specific Noncircular Surface
LOADS/LIMITS
r - Earthquake Loads
s - Boundary Surcharge Loads
t - Limiting Boundaries
u - List of MAXIMUM limits
Select "Help Topic" by pressing the indexed alphabetic letter

Fig. 2.11. Help information accessed by pressing the **F1** key from Main Menu

The user may utilize the **PgDn**/**PgUp** keys to move through the entire "Help-file" one-page at a time, or alternatively may access the Index menu by pressing the **HOME** key. The features associated with the special keys are shown on the top line of each help screen. Pressing the **ESC** key will immediately return the user to the task that was being performed prior to the request for help via the **F1** key.

The information contained in the help screen is read from the XSTABL.HLP file that must be located in the current directory. Since the program must read this information every time the user presses **F1**, a short delay can be expected, especially on personal computers equipped with slow disk drives. However these delays, even on systems with floppy drives only, are not expected to seriously affect the productivity of the user.

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If the index-page is accessed by pressing the **HOME** key, the screen shown in Fig. 2.12 will be displayed. From this display, the user may directly obtain help information for any one of the many available topics. Each topic may be directly accessed by typing the character corresponding to the topic of interest, e.g. press "f" for details concerning isotropic soil properties.

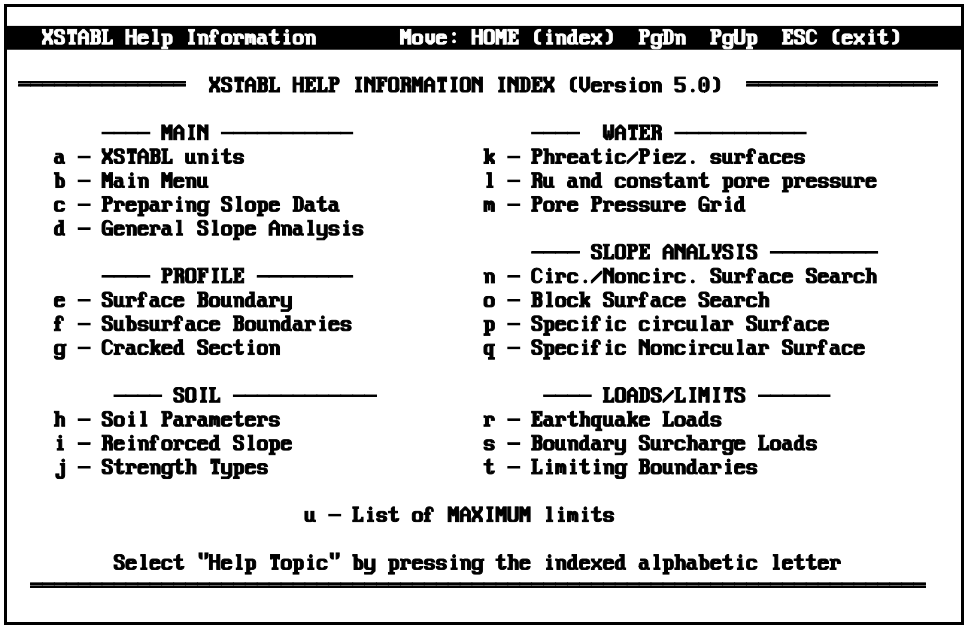
XSTABL Help Information
Move: HOME (index) PgDn PgUp ESC (exit)
XSTABL HELP INFORMATION INDEX (Version 5.0)
MAIN
a - XSTABL units
b - Main Menu
c - Preparing Slope Data
d - General Slope Analysis
PROFILE
e - Surface Boundary
f - Subsurface Boundaries
g - Cracked Section
SOIL
h - Soil Parameters
i - Reinforced Slope
j - Strength Types
WATER
k - Phreatic/Piez. surfaces
l - Ru and constant pore pressure
m - Pore Pressure Grid
SLOPE ANALYSIS
n - Circ./Noncirc. Surface Search
o - Block Surface Search
p - Specific circular Surface
q - Specific Noncircular Surface
LOADS/LIMITS
r - Earthquake Loads
s - Boundary Surcharge Loads
t - Limiting Boundaries
u - List of MAXIMUM limits
Select "Help Topic" by pressing the indexed alphabetic letter

Fig. 2.12. Index of available "help Topics" obtained by pressing the "**Home**" key from any help screen

2.11 Maximum Limits imposed by XSTABL

At any stage of data entry the user may locate information concerning the maximum number of data points allowed by **XSTABL** for the different options. This information is accessed from the help index by selecting the option for "List of Maximum Limits" (press **s** from the index page). At this stage the screen will display the data shown in Fig. 2.13, below.

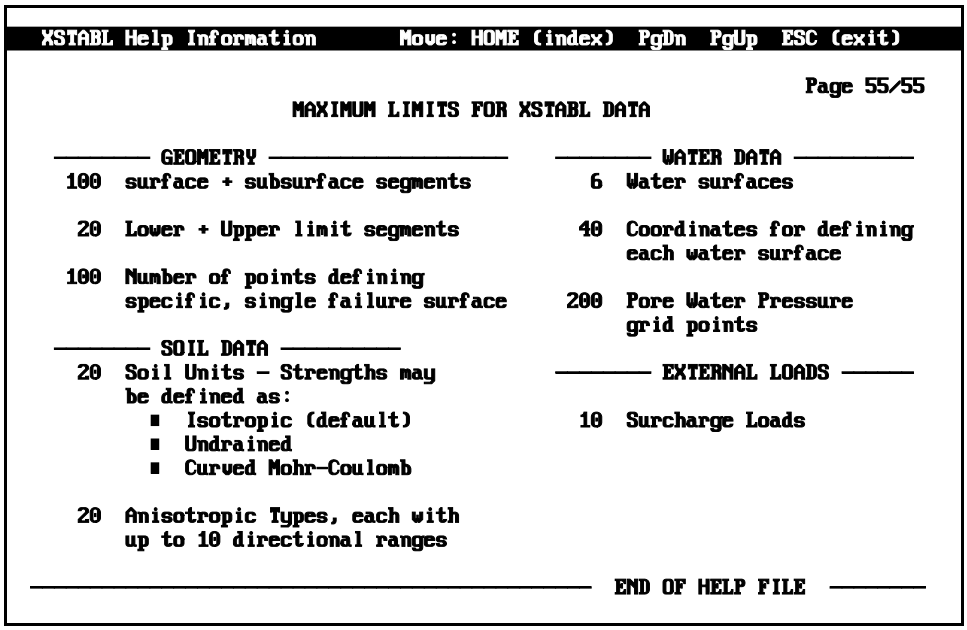
XSTABL Help Information Move: HOME (index) PgDn PgUp ESC (exit)
Page 55/55
MAXIMUM LIMITS FOR XSTABL DATA
GEOMETRY
100 surface + subsurface segments
20 Lower + Upper limit segments
100 Number of points defining specific, single failure surface
SOIL DATA
20 Soil Units - Strengths may be defined as:
Isotropic (default)
Undrained
Curved Mohr-Coulomb
20 Anisotropic Types, each with up to 10 directional ranges
WATER DATA
6 Water surfaces
40 Coordinates for defining each water surface
200 Pore Water Pressure grid points
EXTERNAL LOADS
10 Surcharge Loads
END OF HELP FILE

Fig. 2.13. List of Maximum Limits for **XSTABL** data files

From this list, one can readily determine if any of the limiting criteria are being approached before the maximum number of data points are entered into **XSTABL**. However, please note that **XSTABL** will provide a warning message when the data value corresponding to the maximum number allowed is being entered into the data table.

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2.12 Preview of Slope Profile (F2)

Once the surface boundary has been defined, the user may view a screen plot of the slope geometry by pressing the **F2** key. This option is available from most of the menus and tables, except when the user is being prompted for the name of a file or directory. This is a valuable feature as it helps the user avoid common errors in specifying the coordinates for the slope geometry. Additionally, this option presents a summary of currently defined options in the upper part of the screen, as shown in Fig. 2.14, below.

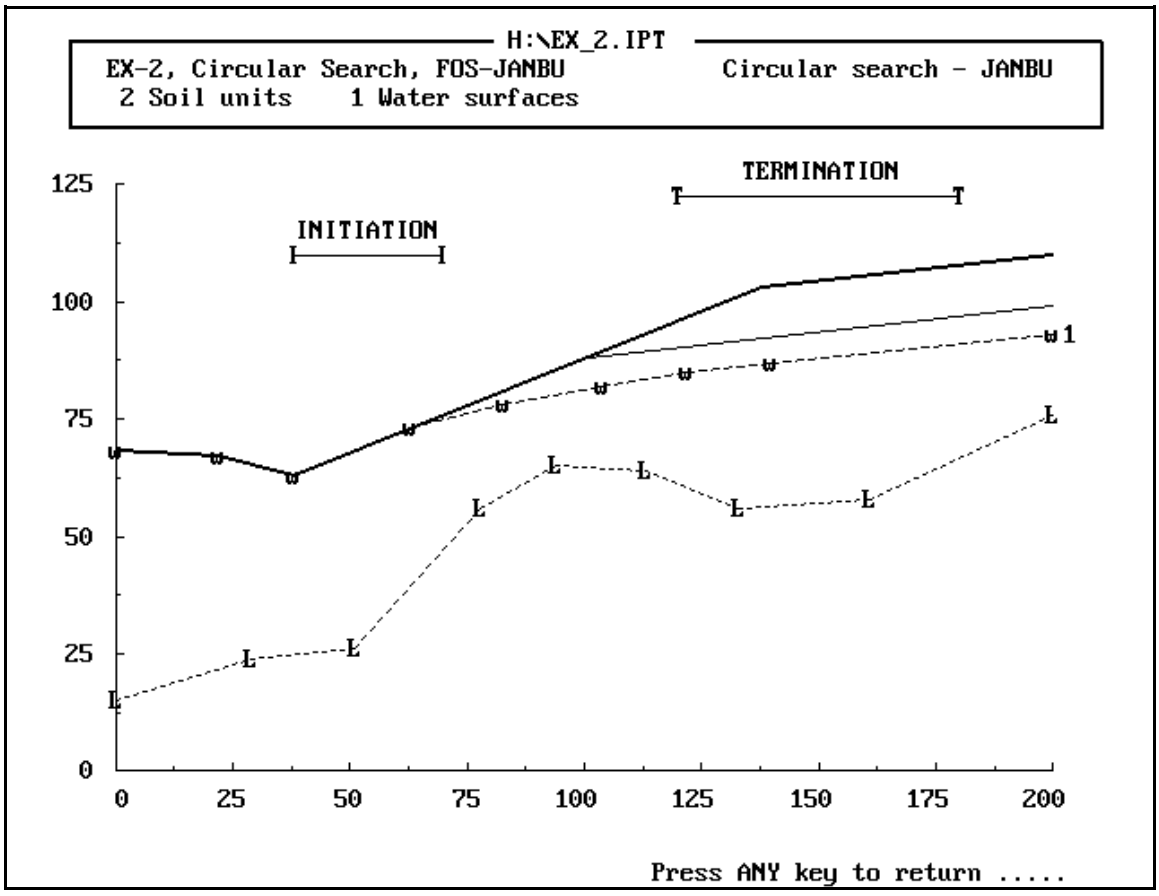

Fig. 2.14. Screen preview of slope geometry obtained by pressing the **F2** key. (figure shows slope geometry from file: EX_2.IPT)

The following information is summarized at the top of each plot, according to the data specified :

Line 1:	Current filename (specified as G:\EX_2.IPT in above figure),
Line 2:	Project name on left side,
	Method of analysis on right side (Circular search – Janbu, in above figure)
Line 3:	Number of soil units
	Number of water surfaces (or Pore pressure grid)
	Earthquake (if seismic coefficients specified)
	Number of Boundary Loads

In addition to the above information, the plot also provides the following:

Limiting Boundaries, Lower/Upper : These limiting boundaries will be identified by a symbol "**L**".

Single Surface : If a single surface, circular or non-circular, is being analyzed, it will be displayed on the screen.

Surface Search Limits : These ranges will be shown as initiation and termination limits and provide the user with a quick view of the potential regions being examined for the most critical failure surfaces.

Water Surfaces : These surfaces are identified on the screen by the following symbols:

"**w**" —— Phreatic Surface

"**p**" —— Piezometric Surface

The number of each such surface coincides with the defined water surface,
i.e. w1, w2 ..... or p1, p2 ... etc.

The hardcopy plots (shown in Chapter 5) from a slope stability analysis also use the same symbols for the water surfaces, while the lower/upper limits are identified by the open triangular symbol: Δ.

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2.13 Note on Plot Scale

The screen plot is suitably scaled to provide the maximum resolution possible within the specified dimensions of the slope geometry. This range is based on an origin corresponding to the minimum slope coordinates and an axis system with lengths of 8 and 5 units for the x and y axes, respectively. The only restriction imposed by the latest version is that the coordinates be less than 99999.9 feet. A screen display of asterisks ("*") in the table is indicative of numbers larger than those permitted by **XSTABL**. Please note that previous versions of **XSTABL** always assumed an origin at (0.0, 0.0).

The plot is scaled according to the maximum range of x and y values encountered in searching the specified slope data for surface and subsurface boundaries, water surfaces, search boxes and lower limits. These maximum values are then suitably corrected to obtain a "pleasant" scale with increments of five feet.

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CHAPTER 3

3.0 DESCRIPTION OF TABLES

The tables are accessed from the "Prepare Slope Data" menu and are used exclusively for editing, entering and reviewing numeric data. A total of *eighteen* data tables are available for entering the slope data. In this chapter, ten data tables that are used to describe the slope geometry, assign soil properties and boundary loads will be discussed in detail. This will permit the user to assemble an input file for the slope configuration under analysis. Chapter five will present details about the available methods of analysis.

A typical table of soil property data from the example file EX_2.IPT is shown in Fig. 3.1. Most of the other data tables are similar and are recognized according to the title shown on the second line. These tables form the ultimate depth within the program structure. After the user has finished entering data, pressing the **ESC** key returns the user to the previous menu.

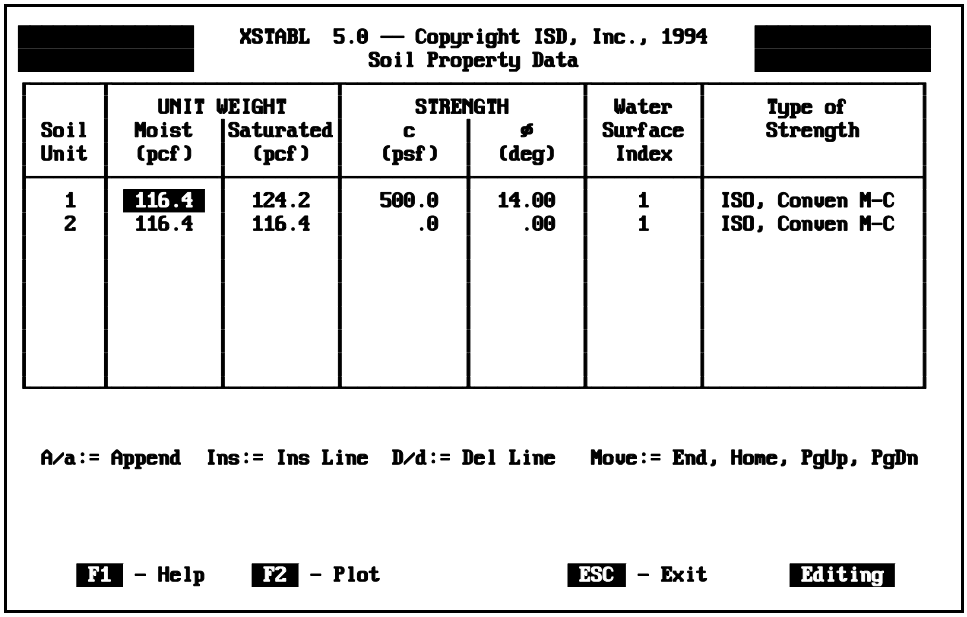

Fig. 3.1. Data table for Soil Properties (isotropic)

Also, in the lower part of the screen (see Fig. 3.1) the user is informed about the specially assigned **F-keys** and the current status of the data entry process by the following words highlighted in the lower right-hand corner.

"**Append**" ——— for automatic, prompted data entry,

"**Editing**" ——— screen editing is in effect.

3.1 Append Mode

Upon initial entry to a table, the program automatically assumes that the user wants to add data and "Append" will be highlighted in the lower right-hand corner of the screen. In this mode, the program continuously prompts the user for data to be entered into each column. The user should type the appropriate values followed by **ENTER**. As part of the error-checking features of **XSTABL**, the program will ONLY accept numeric data (i.e. keys 0-9, the decimal point, and the **–** or + algebraic sign, if appropriate) and will ignore any other keyed entries.

If **ENTER** is pressed without typing any number, *the data value will default to a zero*. At the completion of each row of data, the prompt automatically moves to the next row. In case the user notices erroneous entries, data may be readily edited by transferring from the "Append" mode to the "Editing" mode by pressing the **ESC** key.

While entering data, you may discover that an incorrect value has been previously entered into the data table. In this case you may complete the current line, press **ESC** to change to editing mode and then edit the data value according to the instructions given below. Alternatively, you may complete the entire data-entry process and then change to the editing mode to perform the required corrections.

3.2 Editing Mode

Once all the lines of data have been input, pressing the **ESC** key places the user in the "**Editing**" mode. This will be indicated in the lower right-hand corner of the screen. In this mode, the program allows the user to directly access any value in the table, similar to a full-screen editor, allowing changes to be made quickly and efficiently. If the data extends to more than one screen, the **PgUp**/**PgDn**, **HOME** and **END** keys may be used to rapidly move through many lines of data. This ability to directly access the input data is the most powerful aspect of the **XSTABL** program. Once a data table is completed, the user can return to the previous menu by pressing **ESC**.

Most of the data tables have an intuitive, "user-friendly" feel to their operation. Generally,

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if data has not been entered the program will automatically prompt the user for the numeric values. If the user tries to edit existing data, the program will be placed in the "editing" mode.

3.3 Editing Features

The commands that are available for editing the existing data are summarized, for the convenience of the user, below each table and are discussed below.

A or a Pressing an upper or lower case letter "**A**" will place the program into an **APPEND** mode that is similar to the way data is entered initially. The "**A**"-option should be used to enter data at the **end** of the table.
NOTE -- this is the only way for entering data beyond the current last line.

D or d Pressing an upper or lower case letter "**D**" will delete the current line.

It is important that the user take care in using this operation as the deleted information cannot be recovered !

Ins Pressing the **Insert** key will insert a new line at the current cursor location. Zeroes will be entered into the corresponding line in the table and the user will be prompted to enter new values in the "Append" mode for the current line.

Home Pressing the **HOME** key will quickly take the cursor to the first column entry in Line 1.

End Pressing the **END** key will quickly take the user to the first column of the last line of entry.

PgUp Pressing the **PgUp** key will take the user to the previous page of the table and place the cursor in column 1 at the top of the page.

PgDn Pressing the **PgDn** key will take the user to the next page of the table and place the cursor in column 1 at the top of the page.

← → used to move left or right through single columns.

↑ ↓ used to move up or down through single rows.

3.4 Problem Geometry

Graphical output from the slope analysis is scaled to a 5 x 8 unit display for the screen and hardcopy plots. The hardcopy plot provides a 5 x 8 inch display while the screen units vary according to the available resolution of the hardware (graphics adaptor and monitor). The origin of the coordinate system is set to correspond to the approximate minimum coordinates of the slope geometry in the x and y directions. The scale, incremented in units of five feet, is maximized to fit the range of x, y coordinates within the 5 x 8 plot.

> Please note that this is an enhancement over previous versions of **XSTABL** and allows the user to retain project specific x and y coordinates. Previously, the user would have had to convert station (x) and elevation (y) coordinates to maximize the plot resolution. The only restriction imposed by the latest version is that the coordinates be less than 99999.9 feet. A screen display of asterisks ("***") in a data table is indicative of numbers that are larger than those permitted by **XSTABL**.

3.5 Slope Profile

The slope geometry is entered using the surface and subsurface boundary tables available under the "PROFILE" category. The ground surface and subsurface layers are delineated by "surface" and "subsurface" boundaries that are approximated by straight line segments. Each individual segment is defined by the x,y coordinates of the left and right-end. Any slope configuration can be simulated, left-facing or right-facing, providing the segment order follows a left-to-right sequence and does not contain an overhang. If vertical boundary segments are to be included, these **must** be slightly inclined for computational reasons (e.g. x_{left} = 100.0, x_{right} = 100.1). Since all slope coordinates **must** be positive, the slope is always located in the first quadrant.

A soil unit is assigned to each surface or subsurface segment according to the parameters of the soil directly beneath each segment. Vertical lines passing through the end points of each boundary delineate the lateral extent of the assigned soil unit. Many complex formations (e.g. see Fig. 3.2) may be modeled with this convention. However, the user should note that segments do not have to be the same lengths. The lengths may be varied to suitably model the elevational changes in the slope surface and subsurface soil layers. The example provided in Appendix A should be studied to gain an understanding for geometrically simulating a physical slope for use with **XSTABL**.

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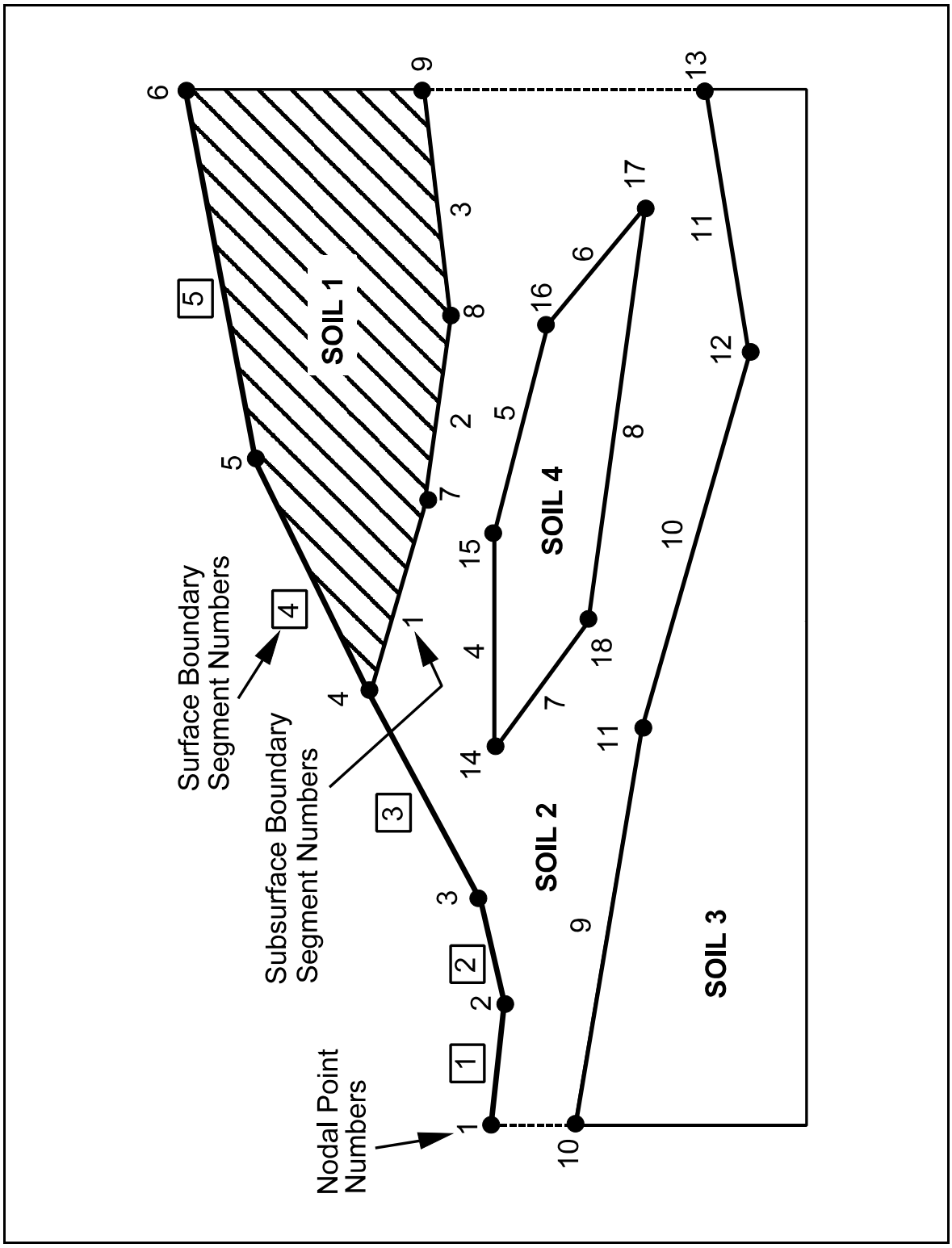

Fig. 3.2. Slope with 4 soil units, 5 surface segments and 11 subsurface segments

The program requires that the surface and subsurface boundaries be specified in a strict sequential order. This ordering scheme requires:

1. Segments of each surface or subsurface boundary to be sequenced such that the slope is defined from left to right. Thus the x-coordinates of the left-end of each segment must increase to retain the required sequence for a surface or subsurface boundary.
2. Subsurface boundaries must be sequenced according to a decreasing elevation below the surface boundary. That is, at any position where a vertical line is drawn, the assigned segment number of the intersected subsurface segments must increase from the ground surface downward. For example, if a vertical line is drawn through node 5 in Fig. 3.2, subsurface segment numbers 2, 5, 8, 10 are intersected in order of decreasing elevation.
3. Boundary segments may not "touch" or intersect other segments. All intersections must occur at nodes. For example, surface segments 3 and 4 and subsurface segment 1 have a common intersection point at node 4 in Fig. 3.2.

Surface Boundary

The surface boundary data for the slope defined by the example data file EX_2.IPT (see Appendix A) is given in the "Surface Boundary" data table presented in Fig. 3.3. The surface of the slope is modeled by five inter-connected segments. The x, y coordinates for the ends of the individual segments are defined in the table along with information concerning the "Soil Unit" located beneath each segment.

Each internal segment (i.e. 2,3 and 4 in example) connects to the adjacent segment such that the right-end coordinates of a particular segment will match the left-end coordinates of the next segment. This is true for all segment end-points except for the **first** and **last** segments. This is shown in Fig. 3.3 where the right-end coordinates of the first segment (22.0, 67.0), are the same as the left-end coordinates of the next segment. Since this results in all internal segment coordinates being duplicated, the program will automatically assign the left-end coordinates of each segment (after the first one) to match the previously entered right-end coordinates.

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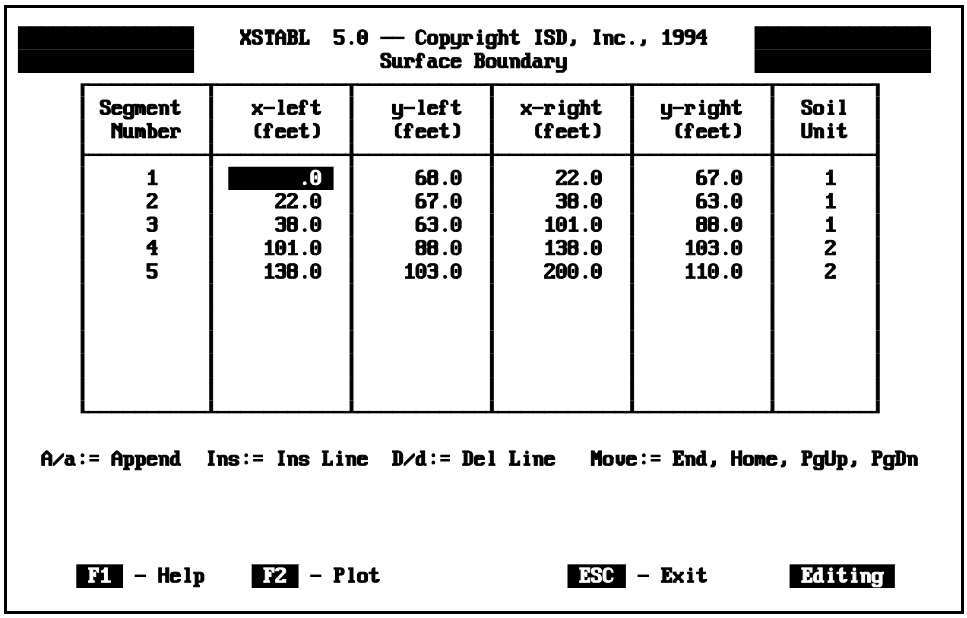
XSTABL 5.0 — Copyright ISD, Inc., 1994
Surface Boundary
Segment Number
x-left (feet)
y-left (feet)
x-right (feet)
y-right (feet)
Soil Unit
1 .0 68.0 22.0 67.0 1
2 22.0 67.0 38.0 63.0 1
3 38.0 63.0 101.0 88.0 1
4 101.0 88.0 138.0 103.0 2
5 138.0 103.0 200.0 110.0 2
A/a:= Append Ins:= Ins Line D/d:= Del Line Move:= End, Home, PgUp, PgDn
F1 - Help
F2 - Plot
ESC - Exit
Editing

Fig. 3.3. Data table for Surface Boundary Segments (file EX_2.IPT)

This automatic entry of coordinates is intended to save the user time and also helps in preventing errors where the left and right-end coordinates fail to agree. At the completion of data entry, pressing the **ESC** key will return the user to the preceding line and turn on "editing" in the lower right-hand corner of the screen.

Inserting/deleting Segments

If the user wishes to insert a "new" segment within existing segments (press the **INSERT** key) the left-end coordinates are automatically written and the user is then only prompted for the right-end coordinates. Once these have been typed and the soil unit assigned, the left-end coordinates on the next line will be also be changed to reflect the addition of a new segment.

The option to delete a segment also works in a similar manner and ensures that adjacent segments retain the same coordinates at the common connecting points.

Subsurface Boundaries

These boundaries, also consisting of inter-connected segments, are used to represent the upper elevation of subsoil layers within the slope. However, unlike the data for the single surface boundary, several subsurface boundaries may be used to define multiple subsoil layers. Thus special attention is needed when the user completes one subsurface boundary and wants to describe the next boundary. Fig. 3.4, below, shows the single subsurface boundary from the slope data of example file: EX_2.IPT.

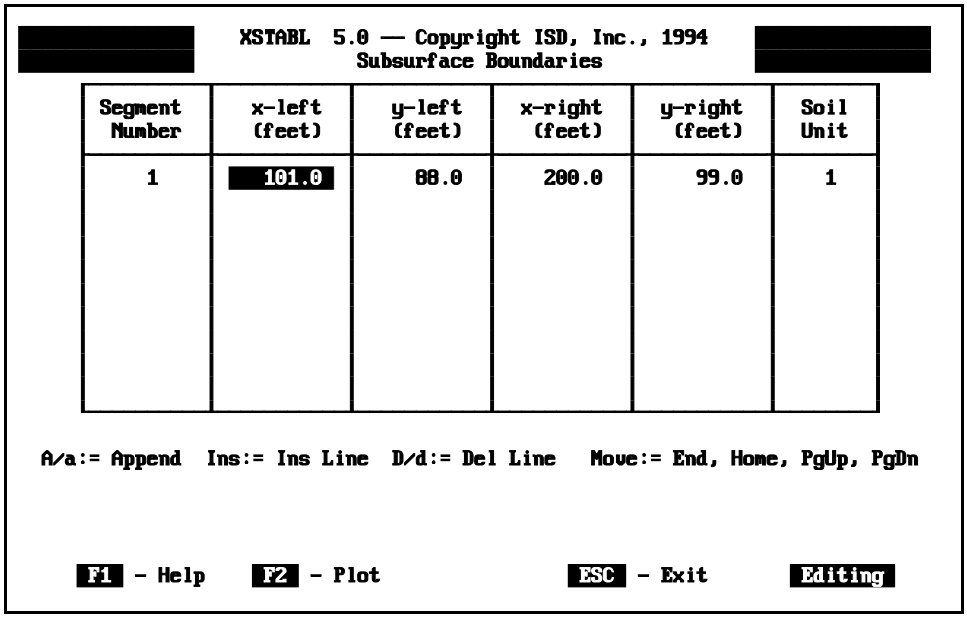

Fig. 3.4. Data table for Subsurface Boundary Segments (file EX_2.IPT)

A more elaborate and detailed example illustrating the development of subsurface boundaries is presented at the end of this section.

First Subsurface Boundary

Data are entered in the same manner as for the "surface" boundary. After typing the right-end coordinates of the last segment used to define the subsoil layer, the user should press the **ESC** key. This signals the completion of the subsurface boundary. At this stage, the cursor will move to column-1 and prompt the user to enter data corresponding to the left-end of the first segment of the next boundary.

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Subsequent Subsurface Boundaries

After entering the left-end data, the program will only prompt for the right-end coordinates for each subsequent segment. Again, after typing the right-end coordinates of the last segment used to define a subsoil layer, the user should press the **ESC** key.

Completion of Subsurface Data

At the stage when all the subsurface boundaries have been entered, the **ESC** key should be pressed twice to return to the "editing" mode. The first **ESC** indicates that the user has finished entering the last segment of a subsoil layer boundary, and the prompt will move to column-1 for the x-left coordinate. When the **ESC** key is pressed for the second time, it signifies completion of ALL data entry for defining the subsurface profile.

Inserting/deleting Segments

If the user wishes to insert a new segment within existing segments (press the **INSERT**-key), the left-end coordinates are automatically written and the user is then only prompted for the right-end coordinates. Once these have been typed and the soil unit assigned, the left-end coordinates on the next line will be changed to reflect the addition of a new segment to the subsurface boundary.

The option to delete a segment also works in a similar manner and ensures that adjacent segments retain the same coordinates at the common connecting points.

Inserting "New" Subsurface Boundaries

At some stage of the analysis, the user may want to insert a "new" subsurface boundary within a set of existing boundaries. In order to take advantage of the automatic prompted approach where only the right-end coordinates are required to define the internal segments, the following procedure should be followed :

1. Move the cursor to column-1 and row corresponding to the location of the first segment for the "new" subsurface boundary. Press the **INSERT** key.

2. The row will clear and you will be prompted for the left and right-end coordinates of the new segment being inserted. Type the two pairs of x, y coordinates for this new segment.

3. Move the cursor to column-1 of the row immediately below the location where a segment has just been inserted. Press the **INSERT** key to insert another segment.

4. Again you will be prompted for the left and right-end coordinates of the new segment.

   Type the left-end coordinates so that they correspond **exactly** to the values that were previously entered for the right-end coordinates of the segment located above the current row. The right-end coordinates of this second segment should then be entered as if this segment was the last in a series of segments used to define this new subsurface boundary. This will effectively create a two segment subsurface boundary that spans across the entire slope profile.

5. Now move the cursor to column-1 of the row where the second "new" segment was inserted. Press the **INSERT** key.

   You should now note that the program will only prompt for the right end coordinates of the new segment being inserted as it is now being inserted within a "newly" defined boundary.

6. Additional segments may now be entered by typing the right end coordinates, moving to the row below, and pressing the **INSERT** key with the cursor in column-1. This sequence (#6) should be repeated for the remaining segments required to define this newly inserted subsurface boundary.

Essentially, **XSTABL** is programmed to recognize the boundaries according to whether the right and left end x-coordinates agree. If there is no agreement, i.e. the segments are not connected, a boundary separation is assumed. However, if you artificially connect two segments across the slope profile, the program assumes that a new boundary has been created. Thus "new" segments can then be inserted within this newly defined boundary, as shown above. This feature is further illustrated with an example in the next section.

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Example Profile

The slope presented in Fig. 3.2 and 3.5 will be used to illustrate several procedures, as discussed above. This is intended to familiarize the user with the data tables for surface and subsurface boundaries. Initially, the slope shown in Fig. 3.5 will be prepared, followed by the insertion of the soil-4 layer depicted in Fig. 3.2. For the convenience of the user, the coordinates of the 18 nodal points shown in Fig. 3.2 are presented in Table 3.1, below.

Table 3.1, Nodal Coordinates for Example Slope

	coordinates			coordinates	
Node #	x	y	Node #	x	y
1	10.0	64.0	10	10.0	50.0
2	31.0	61.0	11	77.0	38.0
3	48.0	65.0	12	140.0	20.0
4	83.0	84.0	13	185.0	27.0
5	122.0	103.0	14	74.0	63.0
6	185.0	115.0	15	110.0	63.0
7	114.0	75.0	16	145.0	52.0
8	146.0	70.0	17	165.0	38.0
9	185.0	75.0	18	95.0	47.0

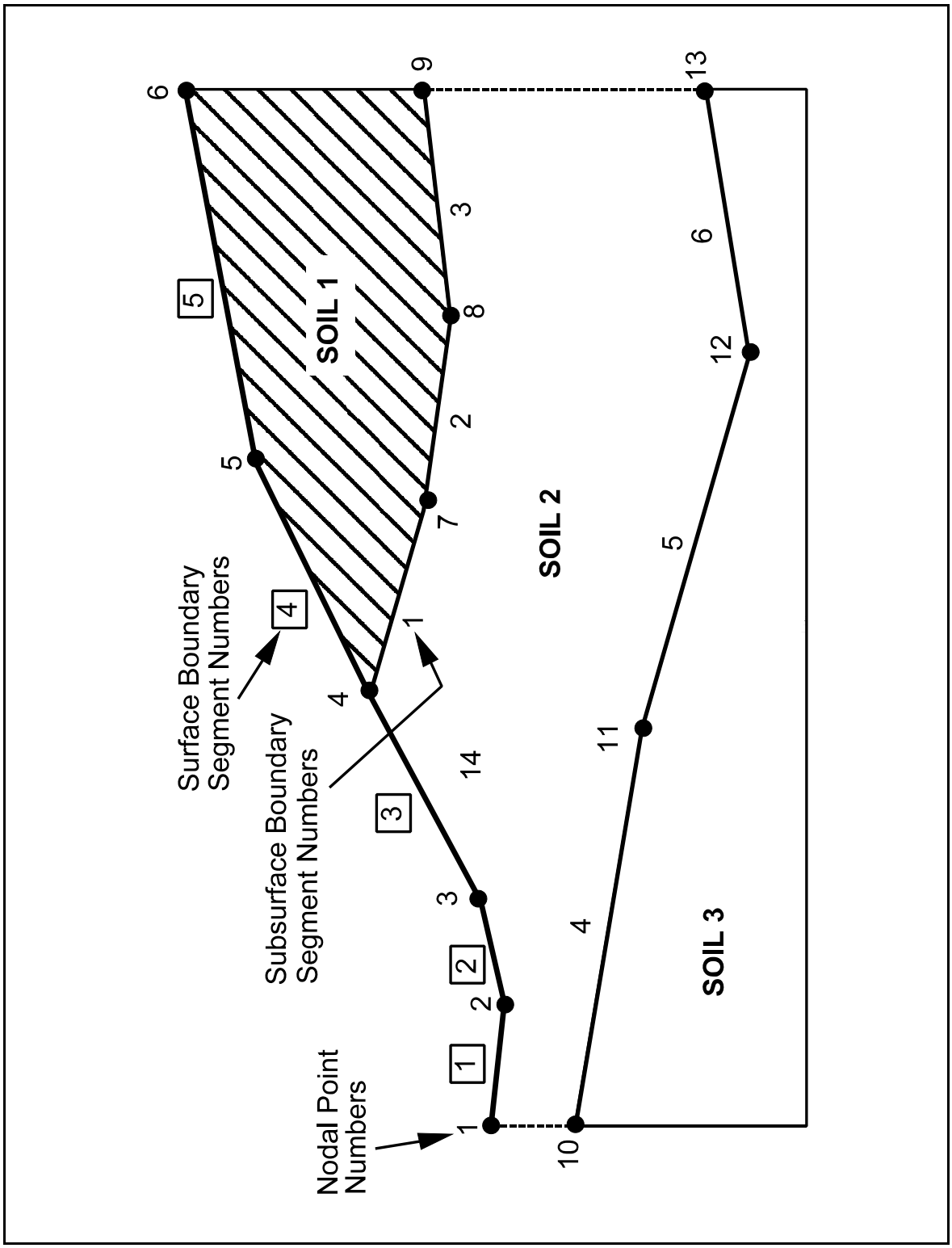

Fig. 3.5. Slope with 3 soil units, 5 surface segments and 6 subsurface segments

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Surface Boundary: The surface boundary consists of five segments shown in Fig. 3.5. For example, the first segment extends from node 1 to 2, and the fifth segment extends from node 5 to 6. The user should follow the sequence and enter the data for the five surface segments, ensuring that segments are entered in a left to right sequence.

Notice how the program only prompts for the right end coordinates after entering the left end coordinates for the first segment. Also, assign the soil unit according to the soil directly below each segment. After entering the surface boundary segments, press **ESC** to exit the "append" mode. At this stage, the data table should look similar to the screen illustrated in Fig. 3.6.

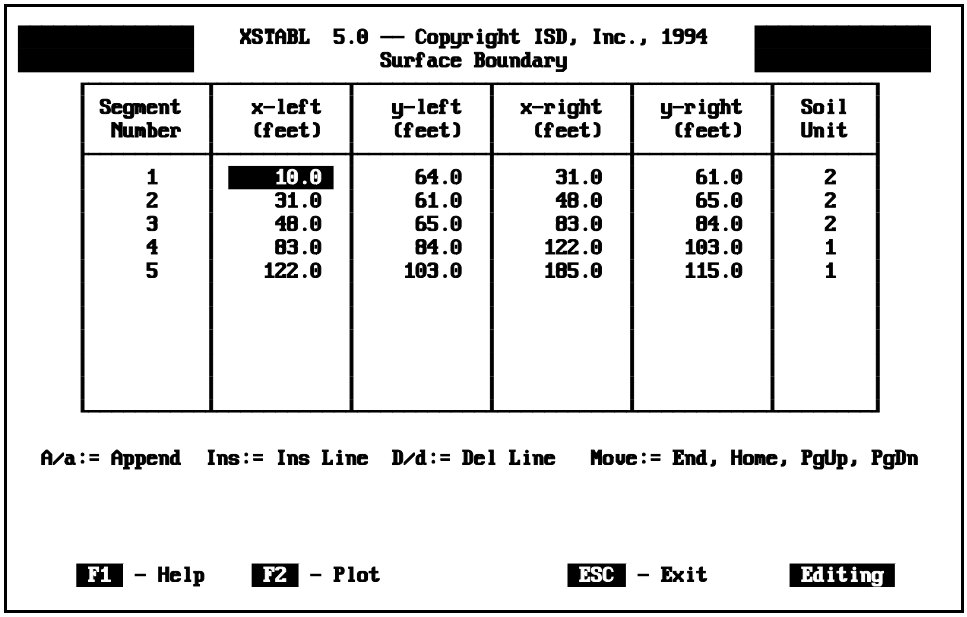
XSTABL 5.0 — Copyright ISD, Inc., 1994
Surface Boundary
Segment Number
x-left (feet)
y-left (feet)
x-right (feet)
y-right (feet)
Soil Unit
1 10.0 64.0 31.0 61.0 2
2 31.0 61.0 48.0 65.0 2
3 48.0 65.0 83.0 84.0 2
4 83.0 84.0 122.0 103.0 1
5 122.0 103.0 185.0 115.0 1
A/a:= Append Ins:= Ins Line D/d:= Del Line Move:= End, Home, PgUp, PgDn
F1 - Help
F2 - Plot
ESC - Exit
Editing

Fig. 3.6. Data table for Surface Boundary Segments for example slope

Once the ground surface boundary has been established, the user may check the profile by pressing the **F2** key to view the slope geometry. Press any key on the keyboard to return to the "Prepare Slope Data" menu to start entering data for the subsurface boundaries.

Subsurface Boundary: There are two subsurface boundaries in the slope shown in Fig. 3.5. The upper boundary consists of segments 1 to 3, and the lower boundary includes segments 4 to 6.

Prepare the subsurface data table by entering the three segments for the upper boundary. The third, and last, segment is defined by the coordinates for nodes 8 and 9. After completing the third segment, the program will prompt for the right end coordinates for segment 4 as if the boundary extends further to the right. However, since the boundary consists of three segments only, press **ESC** to signal the end of the entries for the first subsurface boundary. The program will now prompt for the left end coordinates of the first segment of a "new" boundary. Enter the data for segments 4 to 6. After entering this data, press **ESC** to exit to the "editing" mode. Press **F2** to view the slope geometry. Does it look like the slope in Fig. 3.5. At this stage the data table for the subsurface boundaries should correspond to the data table shown in Fig. 3.7.

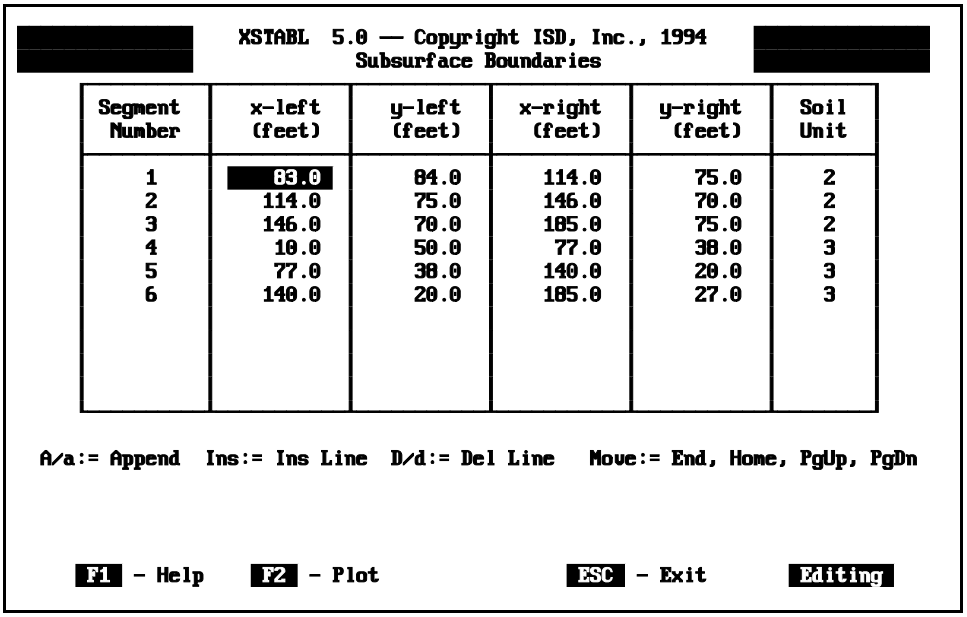
XSTABL 5.0 — Copyright ISD, Inc., 1994
Subsurface Boundaries
Segment Number
x-left (feet)
y-left (feet)
x-right (feet)
y-right (feet)
Soil Unit
1 83.0 84.0 114.0 75.0 2
2 114.0 75.0 146.0 70.0 2
3 146.0 70.0 185.0 75.0 2
4 10.0 50.0 77.0 38.0 3
5 77.0 38.0 140.0 20.0 3
6 140.0 20.0 185.0 27.0 3
A/a:= Append Ins:= Ins Line D/d:= Del Line Move:= End, Home, PgUp, PgDn
F1 - Help
F2 - Plot
ESC - Exit
Editing

Fig. 3.7. Data table for completed Subsurface Boundary Segments for the example slope shown in Fig. 3.5

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Addition of New Segments: The next step includes the insertion of five new boundaries to modify the current slope geometry and develop the slope shown in Fig. 3.2. In order to maintain the required ordering sequence for subsurface boundary segments (see previous section, above), the new soil type will now be bounded by segments 4 to 8, as shown in
Fig. 3.2. This requires inserting five segments into the above subsurface data table.

Segment 4, will be the first segment inserted into the appropriate row in the data table. With the cursor in column-1, and row # 4 (corresponding to segment 4), press the **INSERT** key. Data for the existing segments 4 to 6 will be moved, and you will be prompted for left and right end coordinates for a new segment number five, as shown in Fig. 3.8. Enter the coordinates for nodes 10 and 11 to define this new segment 4.

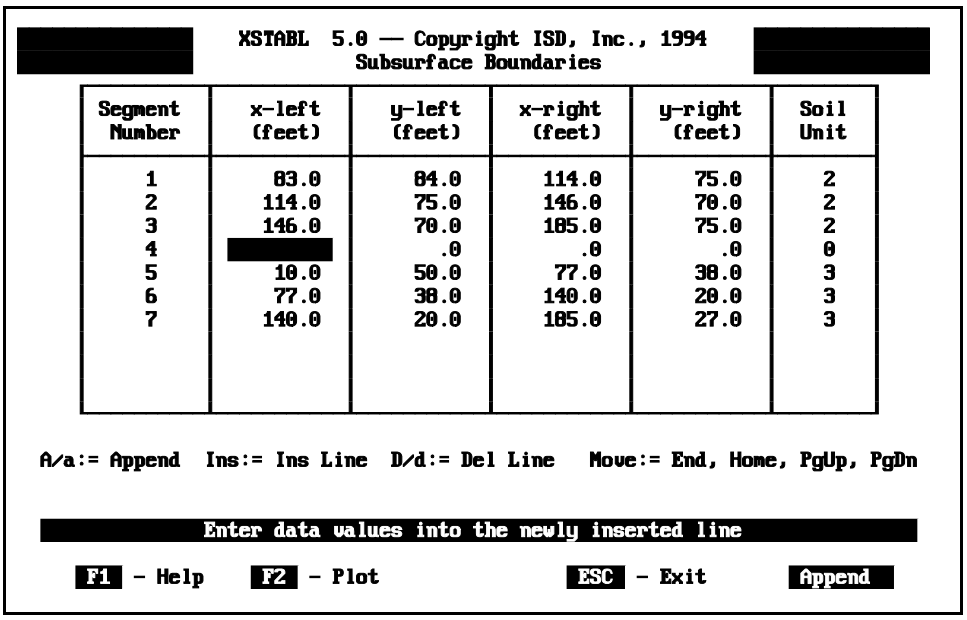
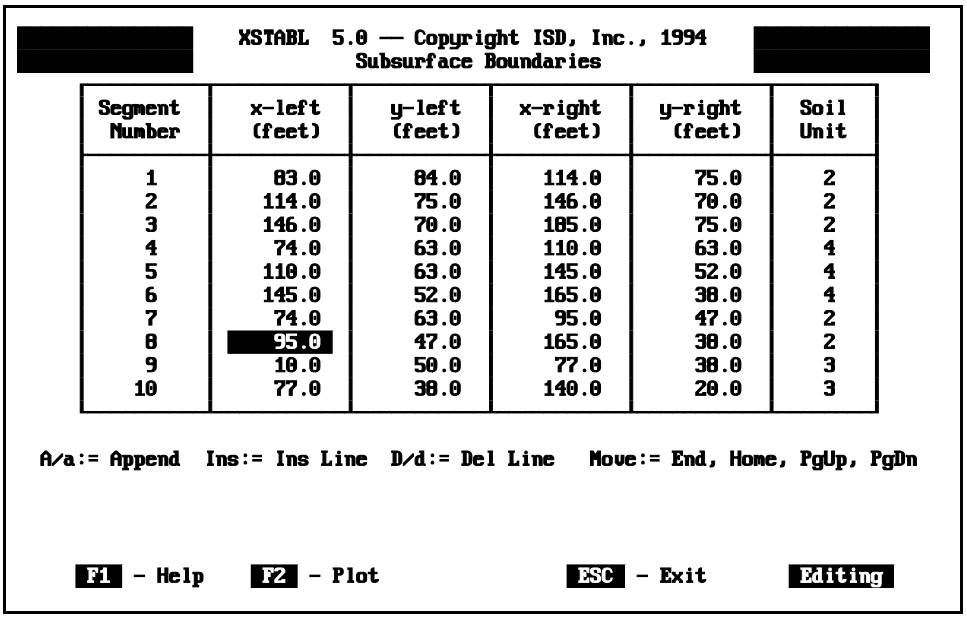

XSTABL 5.0 — Copyright ISD, Inc., 1994
Subsurface Boundaries
Segment Number
x-left (feet)
y-left (feet)
x-right (feet)
y-right (feet)
Soil Unit
1 83.0 84.0 114.0 75.0 2
2 114.0 75.0 146.0 70.0 2
3 146.0 70.0 185.0 75.0 2
4 .0 .0 .0 0
5 10.0 50.0 77.0 38.0 3
6 77.0 38.0 140.0 20.0 3
7 140.0 20.0 185.0 27.0 3
A/a:= Append Ins:= Ins Line D/d:= Del Line Move:= End, Home, PgUp, PgDn
Enter data values into the newly inserted line
F1 - Help
F2 - Plot
ESC - Exit
Append

Fig. 3.8. Data table for Subsurface Boundary Segments. Figure shows effect of pressing the **Insert** key in preparation for the inclusion of the coordinates for segment-4

Next, the user should create a temporary segment five that extends from node 15 to 17, which is really a combination of the final segments 5 and 6. This approach is in accordance with the instructions provided for adding new boundaries. If you press **F2**, the screen plot will show the newly inserted boundary extending from node 15 to 17. Press **INSERT**, and you will be prompted for the right end coordinates for segment five. Enter the coordinates corresponding to node 17, and complete the line by assigning soil unit 4 to this segment.

The last two segments, numbers 7 and 8, may be inserted in a similar manner. Pressing the **F2** key should produce a screen plot similar to the slope shown in Fig. 3.2. The slope is now defined by five surface and 11 subsurface segments. Fig. 3.9 presents the status of the data table after entering the 5 new segments. Notice that the table only displays ten subsurface segments, but you may press the **END** key to view the segment coordinates numbered 2 to 11.


XSTABL 5.0 — Copyright ISD, Inc., 1994
Subsurface Boundaries
A/a:= Append Ins:= Ins Line D/d:= Del Line Move:= End, Home, PgUp, PgDn
F1 - Help
F2 - Plot
ESC - Exit
Editing

Segment Number	x-left (feet)	y-left (feet)	x-right (feet)	y-right (feet)	Soil Unit
1	83.0	84.0	114.0	75.0	2
2	114.0	75.0	146.0	70.0	2
3	146.0	70.0	185.0	75.0	2
4	74.0	63.0	110.0	63.0	4
5	110.0	63.0	145.0	52.0	4
6	145.0	52.0	165.0	38.0	4
7	74.0	63.0	95.0	47.0	2
8	95.0	47.0	165.0	38.0	2
9	10.0	50.0	77.0	38.0	3
10	77.0	38.0	140.0	20.0	3

Fig. 3.9. Data table for Subsurface Boundary Segments after insertion of five **new** segments (# 4 - # 8) which transform the slope shown in Fig. 3.5 to the more complex profile of Fig. 3.2

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3.6 Cracked Section

If a surface layer of soil has a high cohesive strength component, portions of it may include cracks that indirectly control the location of the critical failure surface. For such conditions, the user may define a cracked-zone as part of the slope geometry. This feature is accessed from the PROFILE category, and if selected, **XSTABL** will display the data table shown in Fig. 3.10, below.

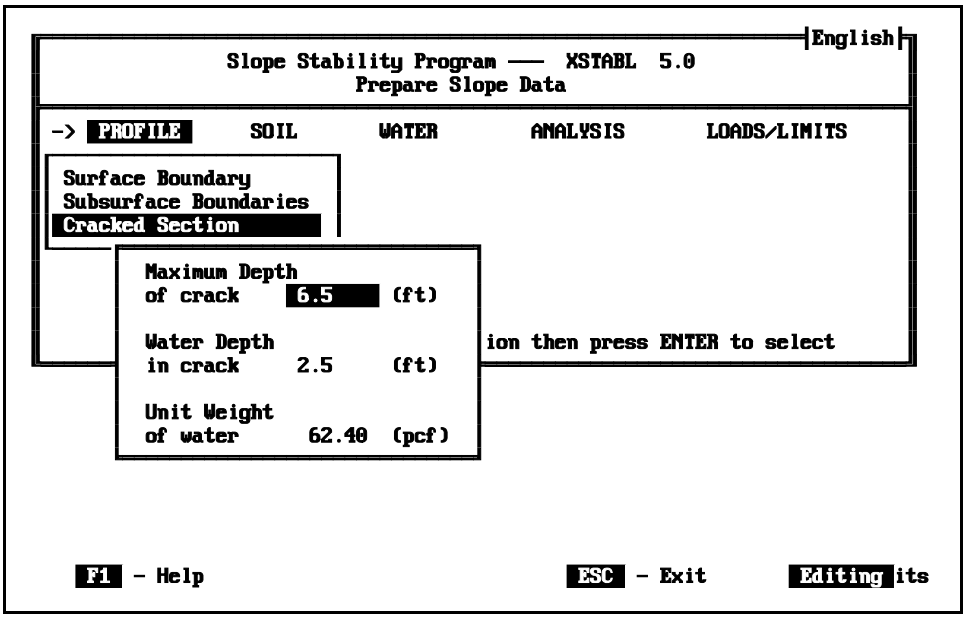

Fig. 3.10. Example data table for assigning a Cracked Section

This table requires the following data:

Maximum Depth of Crack: The maximum penetration of surficial cracks below the defined ground surface;

Maximum Height of Water in Crack: The height of fluid (water) that may be expected within such cracks. **XSTABL** will calculate the hydrostatic force due to this height of fluid and use for the stability analysis. Please note that this force tends to destabilize the slide mass and will result in a lower factor of safety.

Unit Weight of Water: This is the unit weight of the water that has infiltrated into the crack. Typical default values of 62.4 pcf (or 9.81 kN/m^3) for water will be suggested to the user.

XSTABL assumes that the cracked section extends the specified distance below the entire ground surface specified using the surface boundary segments. This assumption is shown in Fig. 3.11 along with the assumed direction and location of the hydrostatic force if the crack is filled with water. With this option the shape of the failure surface, as it extends upwards from the toe of the slope to the crest, will default to a vertical (scarp) once it encounters the specified cracked zone.

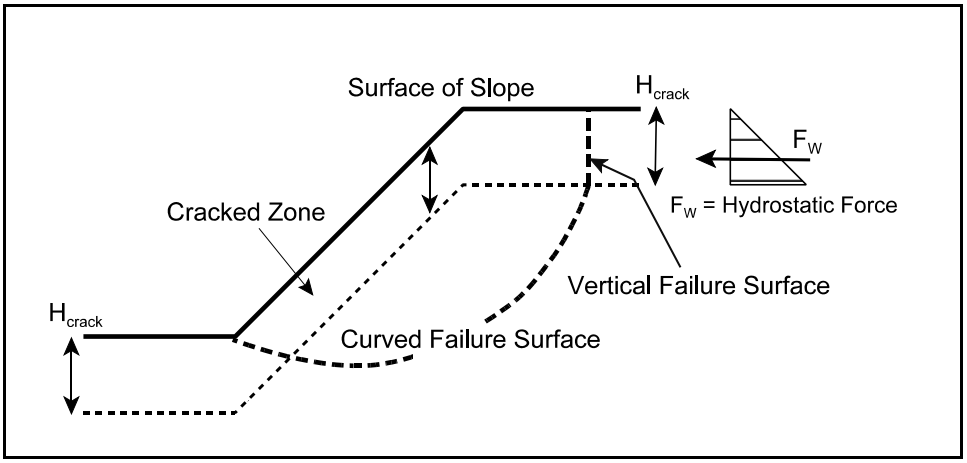

Fig. 3.11. Definition of cracked section and hydrostatic force

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3.7 Soil Parameters

XSTABL uses a soil unit number to uniquely identify the different soils in the slope. The spatial distribution of the soils is then assigned by specifying the appropriate soil unit number corresponding to the soil *beneath* each boundary segment. The parameters for each soil unit are assigned from the "Soil Parameter" option available under the "SOIL" category as illustrated by Fig. 3.12.

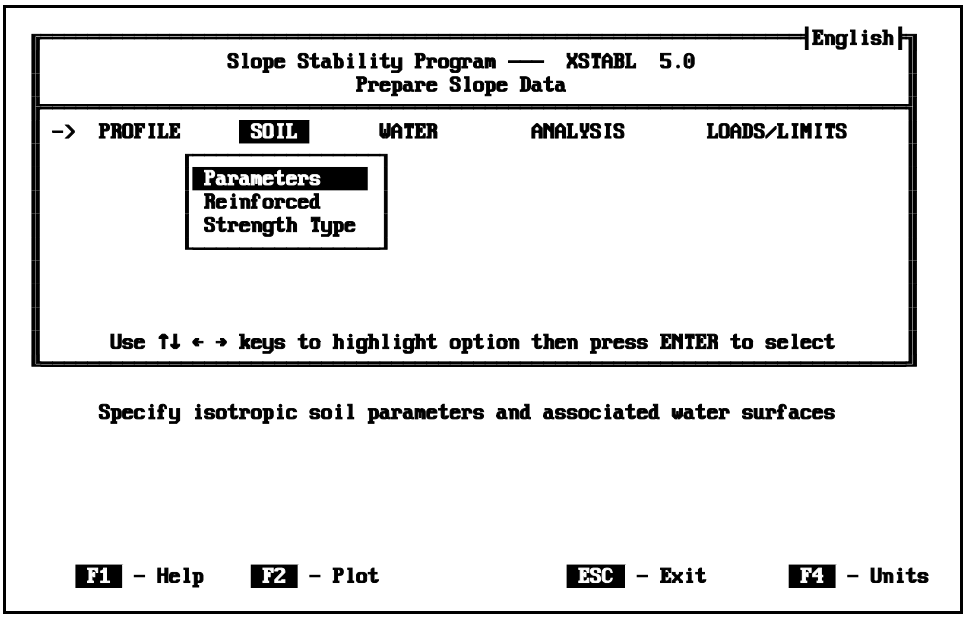

Fig. 3.12. The three options available for selection in the SOIL category

For each soil unit, the following properties are required:

1. **Moist Unit Weight** -- used to calculate the weight of each portion of the discretized slice above the groundwater level,

2. **Saturated Unit Weight** -- used to calculate the weight of each portion of the discretized slice below the groundwater level,

3. **c - value** -- represents the intercept on the Mohr-Coulomb envelope for the strength parameters of the soil,

4. **φ - value** -- represents the slope of the Mohr-Coulomb envelope for the strength parameters of the soil.

The c-φ values are also used to calculate the undrained strength of the soil unit according to the vertical effective stress. In this case, the shear strength is calculated using:

$$s = c + \sigma_v' \tan\varphi \qquad (1)$$

It is possible to specify negative values of c-φ to simulate unique subsoil conditions. The φ value is also used for determining the orientation of the failure segments in the passive and active portions of the block surfaces generated with the RANKINE option and for the initial estimate if the strength of the soil unit is described by a non-linear Mohr-Coulomb envelope.

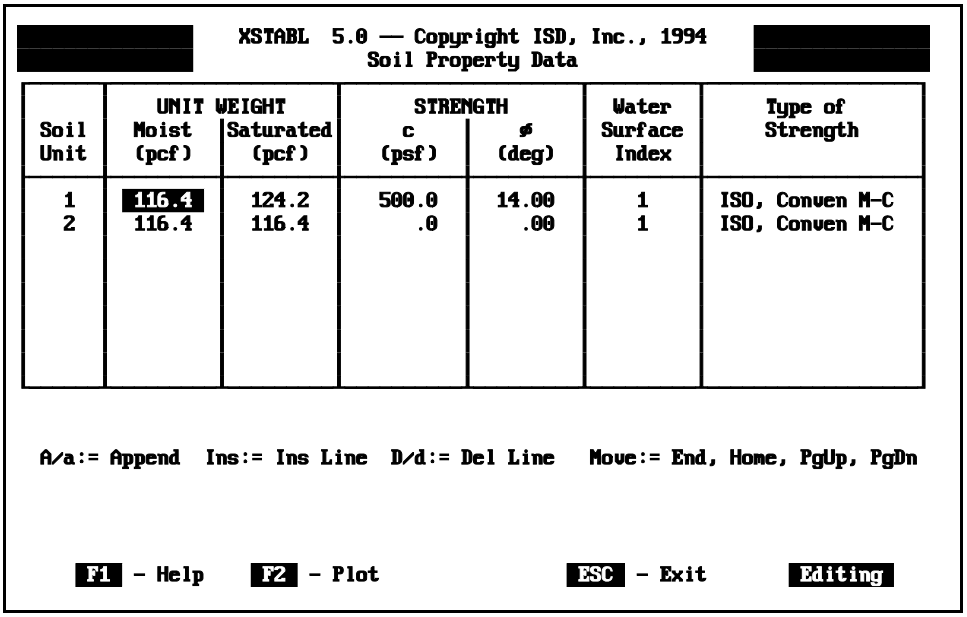

Fig. 3.13. Data table for specifying isotropic soil parameters

5. **Water Surface Index** -- defines a phreatic or piezometric surface that influences the soil layer. A more complete definition and explanation of the pore water pressure conditions is given in section 3.7. If a soil unit is not affected by a water surface, a water surface index of 0 (zero) should be specified in the soil property data table.

   The pore water pressures within a soil unit can also be specified using the R_u-factor (r_u) and a constant pore water pressure. This option is accessed from the "WATER" category.

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The last column within this data table indicates the *type* of strength assigned to the soil unit. This is displayed as:

STRENGTH TYPE	ISOTROPIC	ANISOTROPIC
Conventional	`ISO, Conven M-C`	`ANISO, Conv M-C`
Undrained	`ISO, Undrained`	`ANISO, Undrained`
Nonlinear Mohr-Coulomb Envelope	`ISO, Nonlin M-C`	`ANISO, Nonl M-C`

The program automatically defaults to the isotropic, conventional strength type. However, if the strength is of a different type, these options are set by selecting "Strength Type" from the SOIL category, as shown in Fig. 3.12. *Please note that the data for each soil unit must be assigned in the Soil Parameters Table before selecting the different strength type.*

3.8 Reinforced Slope

A slope may be analyzed with a view to determining the ***amount*** of external force required to maintain a user-specified factor of safety. This feature is selected from the "SOIL" category from the "Prepare Slope Data" menu and SOIL category shown in Fig. 3.12. The data for this option consists of two parameters : (1) the required FOS value and (2) the elevation of the location of the resultant reinforcing force. The elevation is required to determine the magnitude of the required external force for analyses that use the simplified Bishop method, as described in Appendix D.

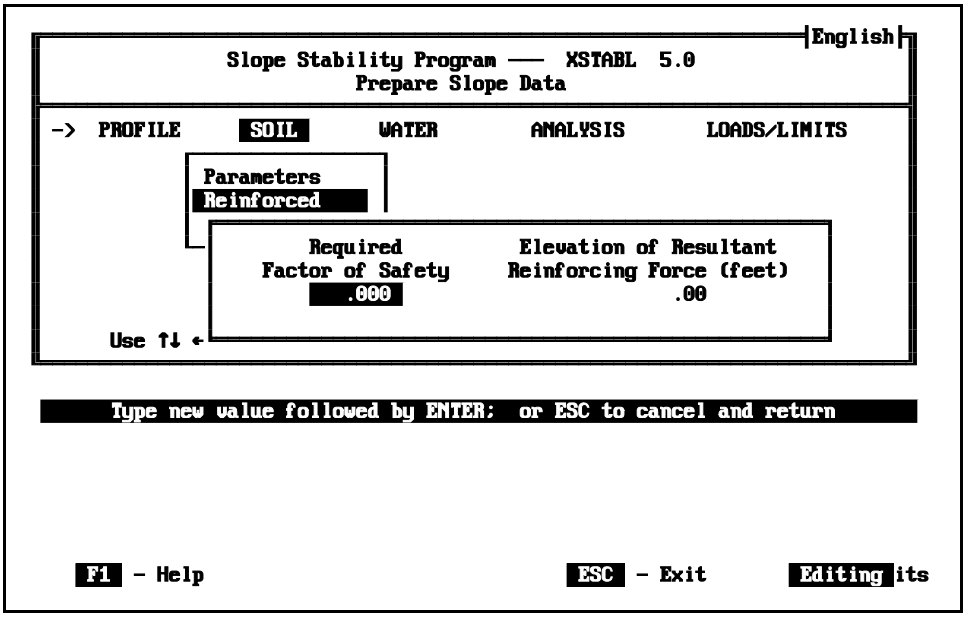

Fig. 3.14. Data table for the reinforced slope analysis. This option requires a user-specified FOS and location of resultant force for the presumed reinforcement stress distribution

Typically, this location is determined from the presumed reinforcement stress-distribution that will be supplied by the reinforcing system. A simple example (Sharma, 1991) is discussed next.

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Reinforcement Example

The following example presents a solution for a 12 meter high, 45° slope with a 40 kPa surcharge. This slope, shown in Fig. 3-15, has been presented as an example problem by Koerner (1991). The reinforced slope analysis allows the user to determine the magnitude of external force necessary to maintain a specified factor of safety (FOS). In this example, the slope is to be designed for a FOS = 1.5 and reinforcement will be provided for the entire 12 meter height of the slope.

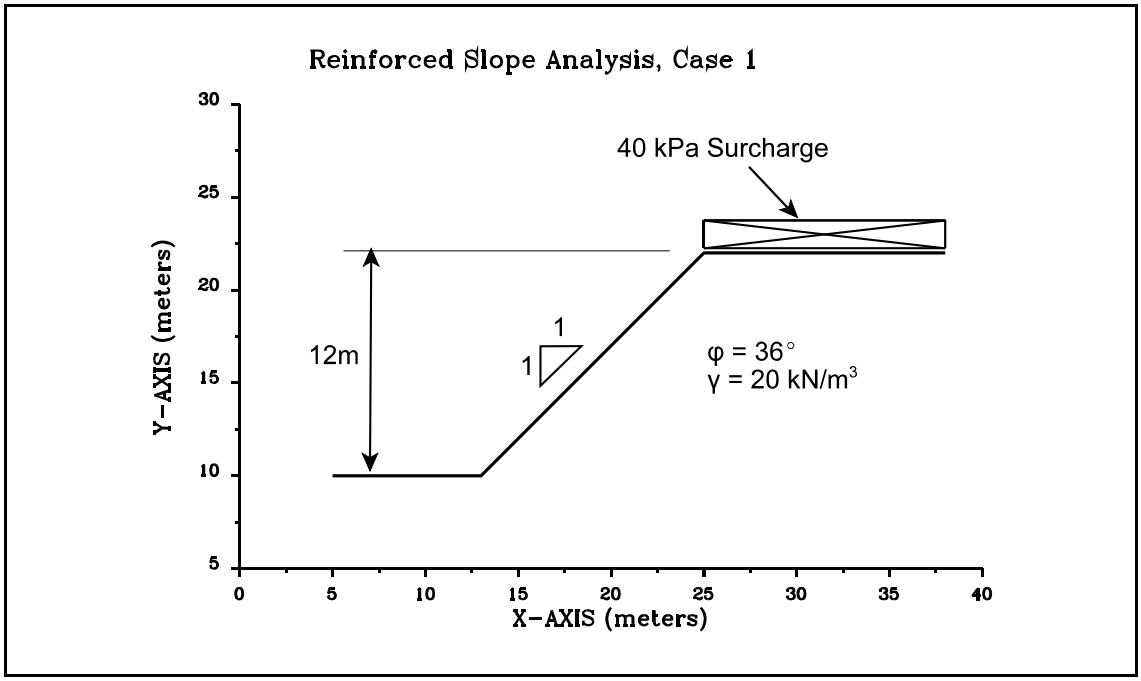

Fig. 3.15. Slope for reinforced soil example

In using the reinforcement option, the critical surface shown in Fig. 3.16, was found to require a horizontal external force of 345 kN, per lineal meter, to maintain the necessary design FOS > 1.5. This force may be simulated by a triangular stress distribution that varies from zero to 57.5 kPa.

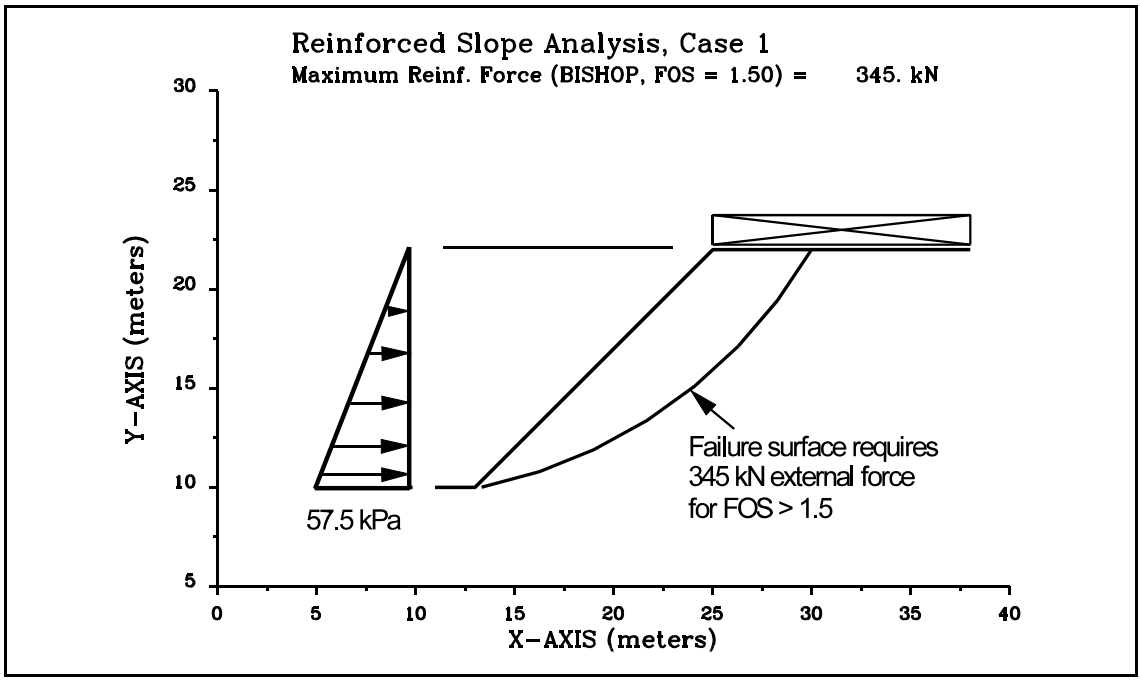
Reinforced Slope Analysis, Case 1
Maximum Reinf. Force (BISHOP, FOS = 1.50) = 345. kN
Y-AXIS (meters)
X-AXIS (meters)
57.5 kPa
Failure surface requires
345 kN external force
for FOS > 1.5

Fig. 3.16. Comparison of failure surfaces for unreinforced slope and surface requiring maximum external force

Following the reinforced analysis, **XSTABL** is used to assess the stability of the unreinforced 45° slope. The analysis reveals that the slope has a minimum FOS, $F_{crit} = 0.734$ for the critical surface shown in Fig. 3-17. The surface, requiring the 345 kN of external support is also shown in the same figure for comparison. If the reinforced slope must maintain a minimum FOS > 1.5, the strength parameters of a reinforced zone are determined according to Eqs. 2.23 and 2.24:

$$F_r = \frac{F_{min}}{F_{crit}} = \frac{1.5}{0.734} = 2.044$$

$$\varphi_{reinf} = \tan^{-1}\left[2.044 \tan(36°)\right] = 56.04°$$

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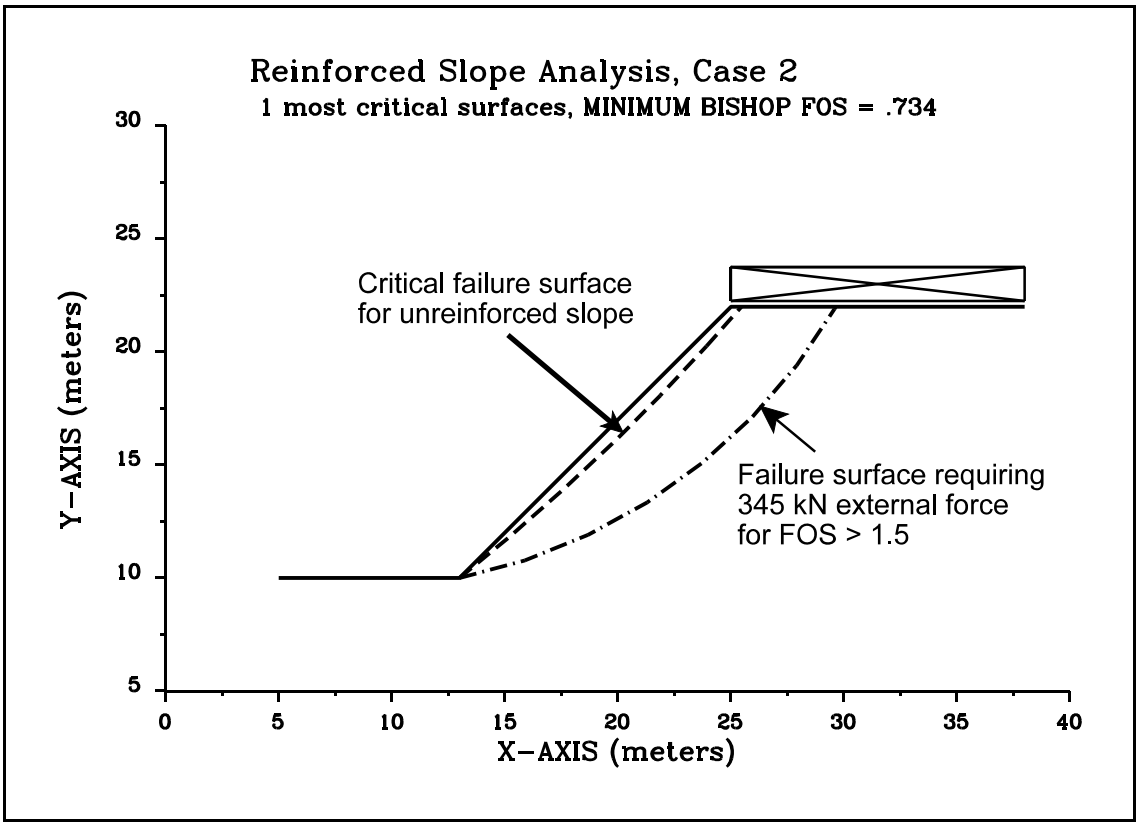

Fig. 3.17. Comparison of failure surfaces for unreinforced slope and surface requiring maximum external force.

Next the analysis is repeated by including a reinforced zone, with $\varphi = 56.04°$, as shown in Fig. 3-18. The critical surface, with a FOS > 1.5, is determined using an iterative process, which varies the lateral extent of the reinforced zone manually. The required reinforced region should correspond to the case where the critical surface has a FOS > 1.5. The reinforcing zone specified for this analysis is used to satisfy the criteria for ***external*** stability. The results of the above analysis may be summarized as:

1. Required reinforcement force = 345 kN,
2. Reinforced zone extends *at least* 7.5 meters into the slope.
   (The FOS for a 6 meter reinforced zone was 1.412)

Please note that the reinforcement must be longer than 7.5 meters to ensure that adequate embedment is available to resist the anticipated tensile forces. This embedment length depends on the reinforcement type, spacing and the magnitude of the design force and cannot be determined using **XSTABL**. A ***minimum*** embedment length of 1 meter, or 3 feet, is generally recommended for the design of steep reinforced slopes.

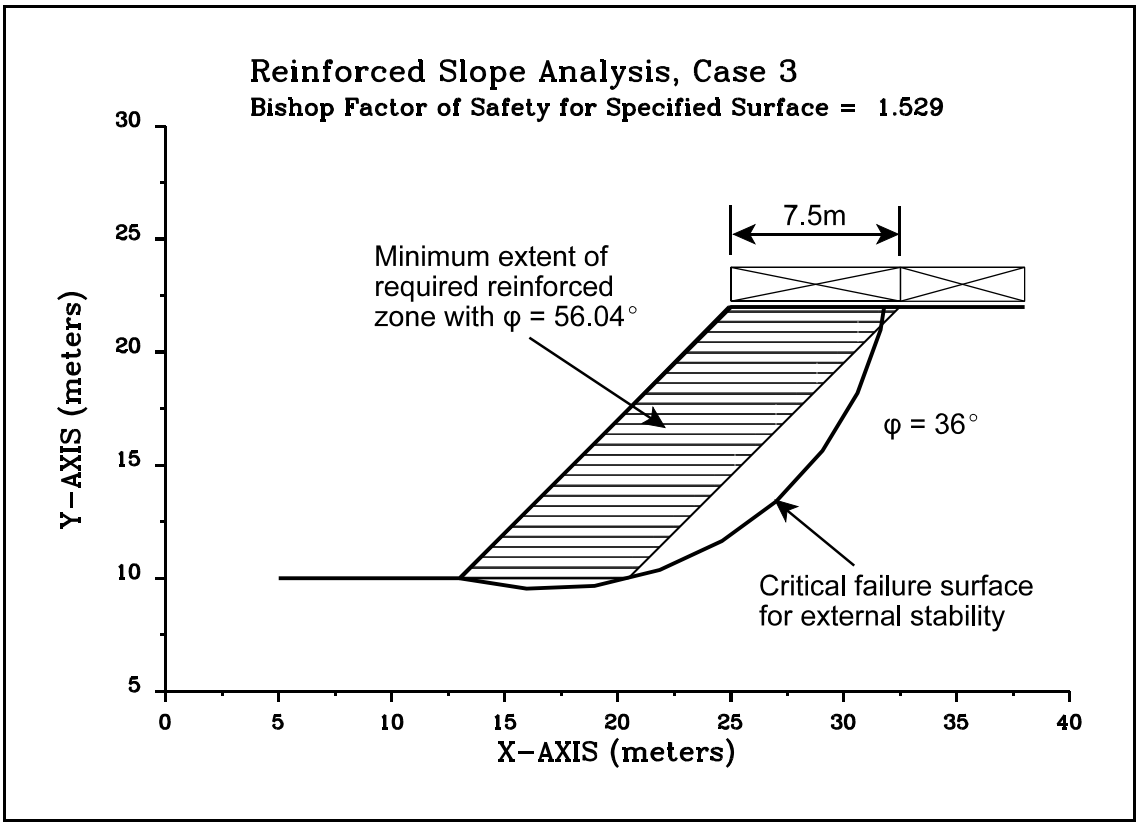

Fig. 3.18. Comparison of failure surfaces for unreinforced slope and surface requiring maximum external force.

For the same problem, Koerner (1991) calculated an external force of 294 kN and a reinforcement length that ranges from 8 meters at the crest to 11 meters at the toe of the slope. Koerner's solution requires 85 percent of the force calculated using **XSTABL**, but the extent of the required reinforced zone, based on a minimum 1 meter embedment, is 27 percent *larger*.

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3.9 Strength Type

Upon selecting this option, the data table shown in Fig. 3.19 is displayed with the default isotropic conventional strength type assigned to the soil units. The options in this table may be readily changed by using the *spacebar* key to toggle through the different labels. In the case of the strength type, pressing the spacebar cycles through the three different strength types: (1) conventional, (2) undrained and (3) nonlinear M-C.

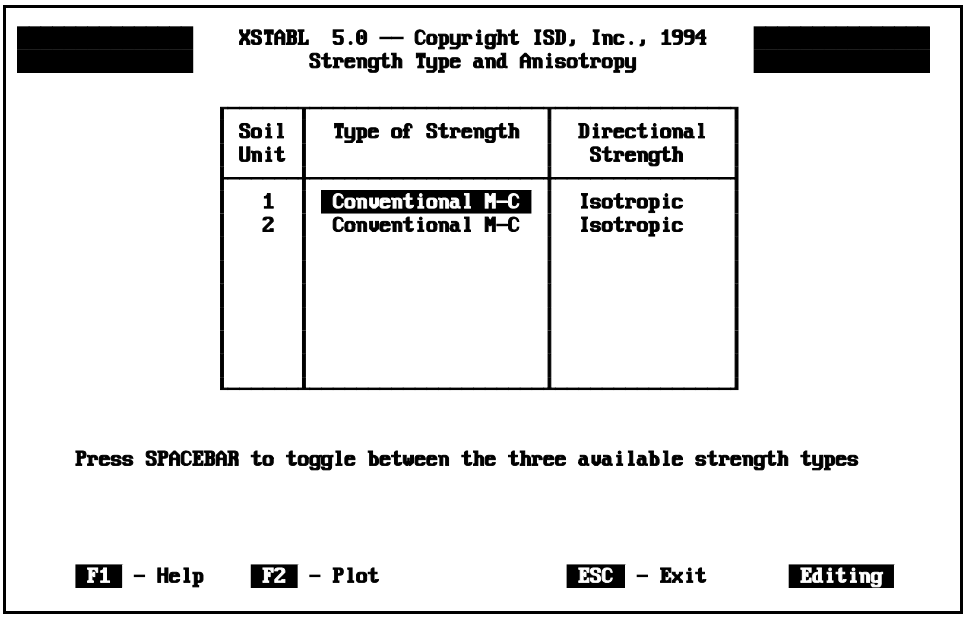

Fig. 3.19. Data table for assigning strength type

Nonlinear Mohr-Coulomb Strength

If the Nonlinear Mohr-Coulomb (NLMC) option is selected via the toggle key, and then the ENTER key is pressed, the user will be presented with the data table shown in Fig. 3.20 for entering the normal stress-shear strength values.

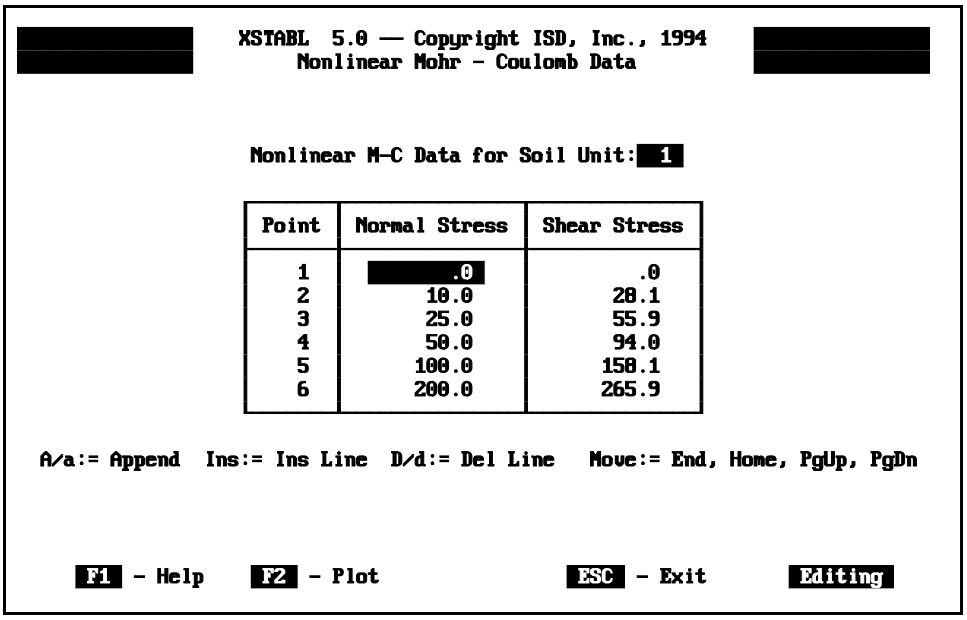

Fig. 3.20. Example data table for NLMC strength envelope

As an improvement in version 5.00, the user may import the σ-τ values from a previously created data file that has been given the *.NLM extension. The ability to select from a list of valid filenames is provided via the F3 key. If you do not wish to import any data, a "n" response to the prompt will set the data table into an append mode for entering the σ-τ data directly. After data has been entered for the selected soil unit, pressing the **ESC** key terminates the automatic entry phase. Upon pressing **ESC** again, **XSTABL** return the user to the Strength Type table (Fig. 3.19).

Unlike the NLMC option, the conventional and undrained options do not require further data. The changes made within this table are automatically reflected in the Soil Parameter table, previously shown in Fig. 3.13.

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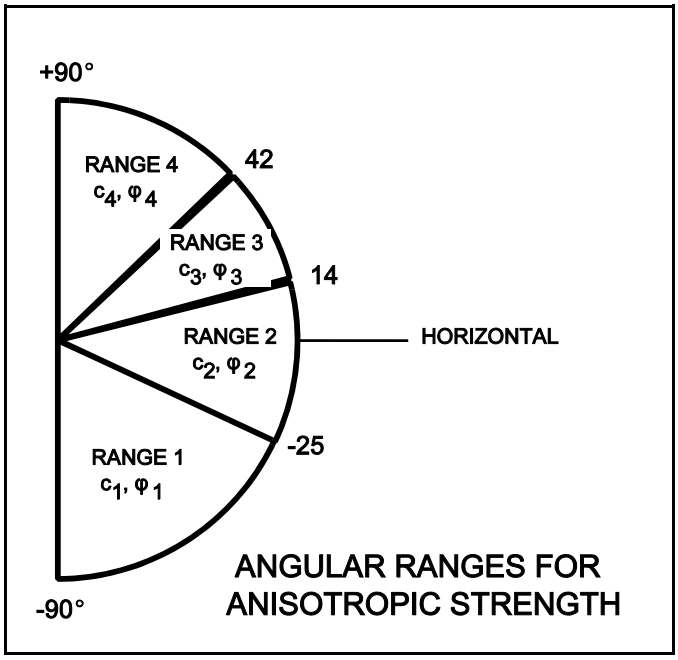
Anisotropic Strength

Anisotropic strengths are also assigned from the Strength Type table (Fig. 3.19). The spacebar is again used to toggle between isotropic and anisotropic in the second column. With the option changed to "Anisotropic", pressing the ENTER key accesses the Anisotropic Data table for assigning the strength parameters according to the inclination of the base of the slice. *These anisotropic strengths can be assigned for* ***Conventional*** *and* ***Undrained*** *strength parameters only.*

Soils exhibiting anisotropic strength properties are described by assigning the Mohr-Coulomb strength parameters (i.e. c and φ) to discrete angular ranges between -90° and +90°, measured counterclockwise from the horizontal. Then, depending on the angle of the base of each discretized slice, the appropriate c and φ values are selected from one of the specified ranges for computing the factor of safety.

Each directional range is established by sequentially specifying the discrete ranges beginning from -90° and finishing at +90° in a counterclockwise order. Thus a minimum of two ranges is required to simulate anisotropic behavior. The defined anisotropic data must be referenced to a soil unit number that is also described in the isotropic soil property data table. Fig. 3.21 illustrates an example of an anisotropic soil modeled by four angular ranges with the following strength parameters :



Range 1:
from -90.0° to -25.0, – c_1, φ_1

Range 2:
from -25.0° to 14.0, – c_2, φ_2

Range 3:
from 14.0° to 42.0, – c_3, φ_3

Range 4:
from 42.0° to 90.0, – c_4, φ_4

Fig. 3.21. Example of anisotropic strength parameter ranges

For example, if numeric data are substituted for the above c_i and φ_i values, the above data will appear as shown in the anisotropic data table presented in Fig. 3.22, below.

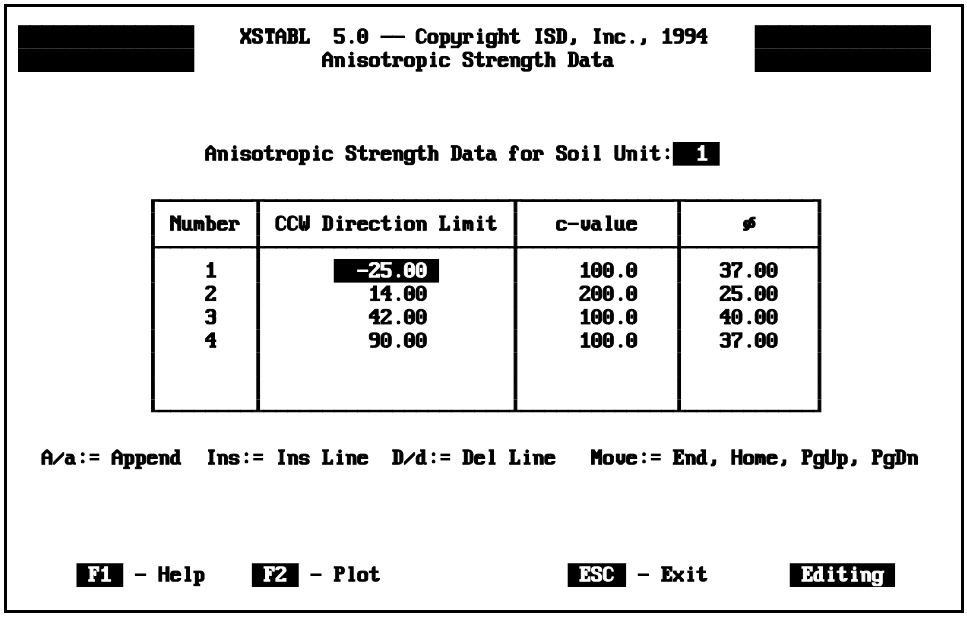


Fig. 3.22. Example data table for anisotropic parameters

Please note that all other soil properties of the anisotropic soil unit must be described initially within the Soil Parameters data table. After defining the anisotropic strength parameters for a soil unit, pressing the **ESC** key returns the user to the Strength Type table, Fig. 3.19.

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3.10 Pore Water Pressures

Pore water pressures for slope stability analysis may be assigned using: (1) water surfaces, (2) r_u factors, (3) constant pore pressures within a soil unit, and (4) pore water pressure grid. In **XSTABL**, these options may be accessed from the WATER category, as shown in Figure 3.23, below.

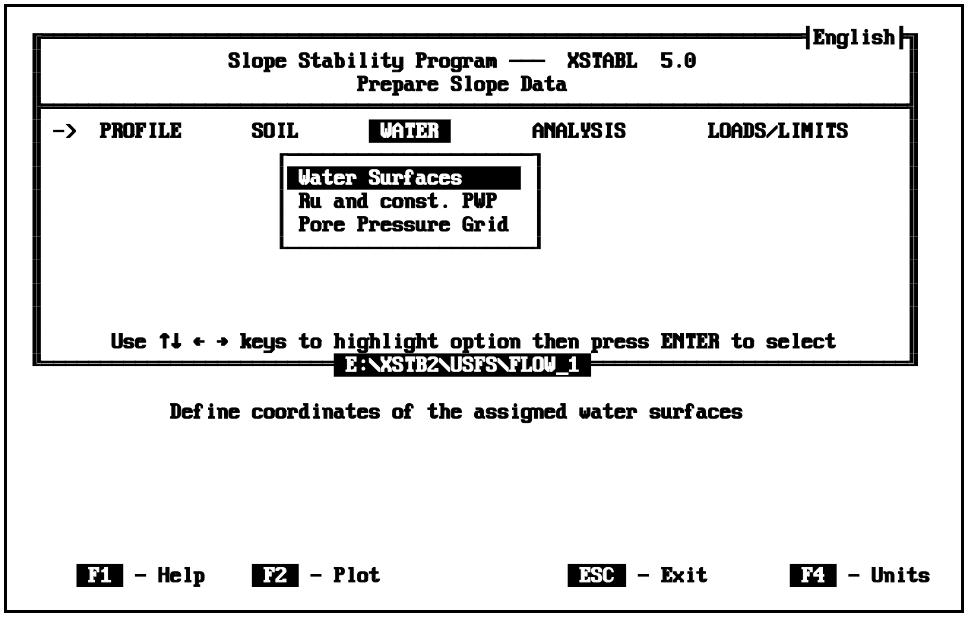

Fig. 3.23. Options available from the WATER category

Water Surfaces

If the "Water Surfaces" option is selected, the user is prompted initially to enter a value for the unit weight of water that will be used to compute the pore water pressures. Following this entry, the Water Surface Type table (Fig. 3.24) is presented for selecting the type of water surface.

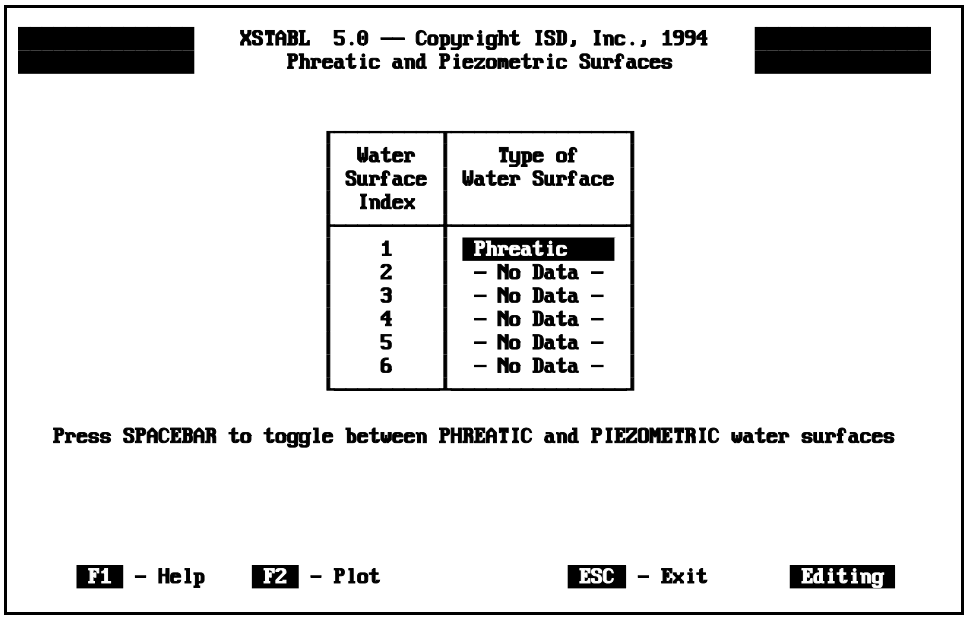

Fig. 3.24. Table for selecting water surface as either: (a) phreatic or (b) piezometric surface (file EX_2.IPT)

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All water surfaces are associated with soil units, and are used to represent **phreatic** or **piezometric** surfaces for calculating pore water pressures along the potential failure surface. After selecting the type of water surface, i.e. phreatic or piezometric, pressing the ENTER key will present the user with the Water Surface data table (Fig. 3.25) for entering the x, y coordinates.

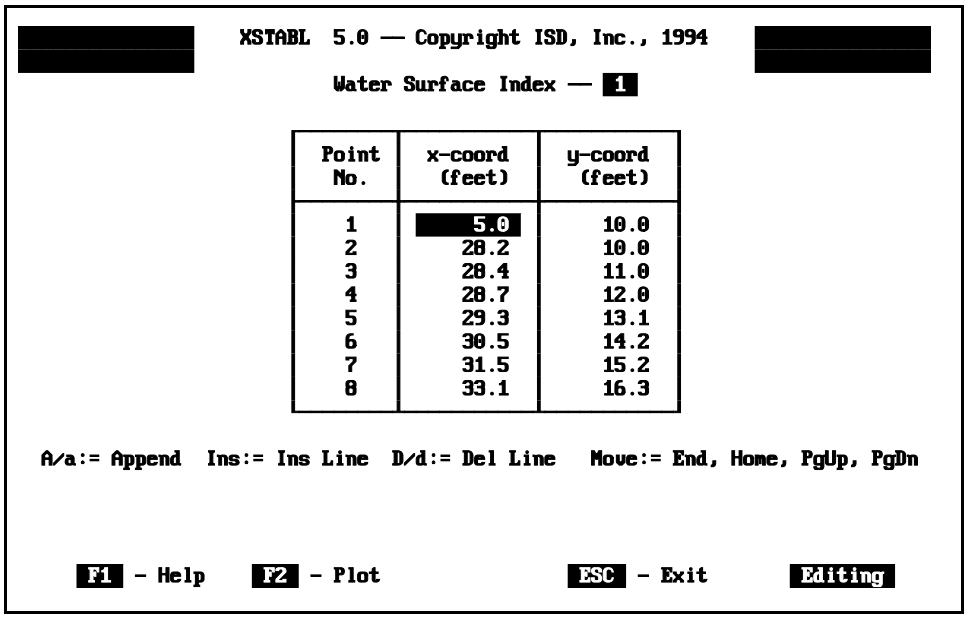

Fig. 3.25. Example data table for assigning water surfaces (file EX_2.IPT)

If used, the water surfaces *must* be defined continuously across the horizontal extent of the region to be investigated for possible failure surfaces and preferably across the entire slope geometry defined by the surface and subsurface boundaries. **XSTABL** assumes zero pore water pressure at points within the soil mass if a water surface is not defined across the failure surface zones. Each water surface is defined by a series of x and y coordinate points connected by straight line segments. The data must be ordered to progress from left to right.

In general, the phreatic surface approach is more realistic and will calculate a higher effective strength. However, if piezometers have been installed, and pore water pressure data is available along a potential failure surface, the piezometric surface approach should be employed for the analysis.

Phreatic Surfaces

These represent the free ground water level within the slope. In most slopes this groundwater level will be inclined, indicating groundwater flow. Such conditions require that the pore water pressure calculations account for seepage losses. This requires the determination of the equipotential line passing through the center of the slice base.

> It is important that the user not confuse phreatic and piezometric surfaces. If the inclination of the water surface is small (i.e. < 5°), the results of the analysis will only be affected slightly. However for larger angles, the calculated pore water pressures will be ***significantly*** different, with piezometric surfaces always generating higher pore pressures than the phreatic surfaces.

If the equipotential line is assumed to be a straight line, the inclination of the phreatic surface and the magnitude of the vertical distance between the phreatic surface and the slice base may be used to estimate the pore water pressure head. This is illustrated in Fig. 3.26. If the phreatic surface is inclined at an angle θ from the horizontal and the vertical distance is h_w, the pore water pressure head will be $h_w \cos^2 \theta$. In cases where a phreatic surface is located above the ground surface, hydrostatic pressures are assumed to act upon the ground surface boundary.

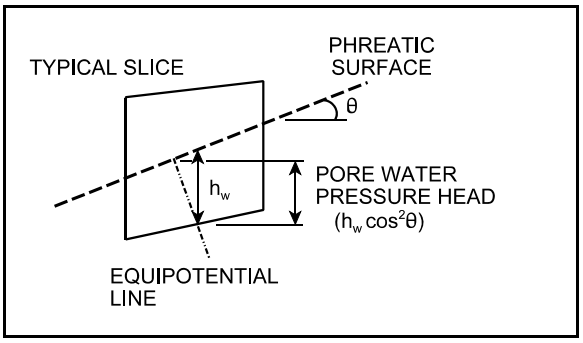

Fig. 3.26. Calculation of pore pressure head for a phreatic surface

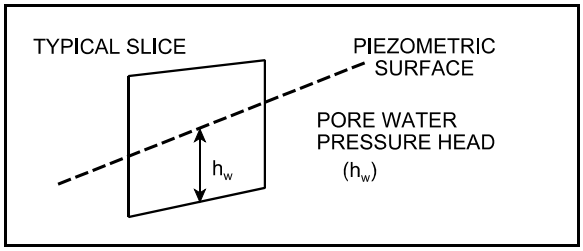

Fig. 3.27. Calculation of pore pressure head for a piezometric surface

Piezometric Surface

This represents the actual pressure head *relative to a surface within the slope*. This relative surface, in two dimensions, will correspond to a line such as a potential failure surface. This option should only be used to examine the stability of single surfaces, or for a back-analysis of an actual slope failure. Pore water pressures are calculated according to the vertical distance between the base of the slice and piezometric surface corresponding to the appropriate soil unit (refer to Fig. 3.27).

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3.11 Pore Pressure Parameters

Pore water pressures in a soil unit may also be assigned using either the r_u factor or a constant pore water pressure. This option is selected form the WATER category and data is entered into a table similar to the one shown in Fig. 3.28, below. Data for this option consists of:

r_u- factor -- used to model the pore water pressures as a fraction (r_u) of the *total vertical earth pressure* within the slope. Please note that this vertical earth pressure will not include any surcharge pressures, if specified.

Constant Pore Pressure -- this option allows the user to specify a constant pore water pressure for <u>all</u> points within a soil layer,

Please note that these values can only be set for the soil units that have been assigned previously in the Soil Parameter table.

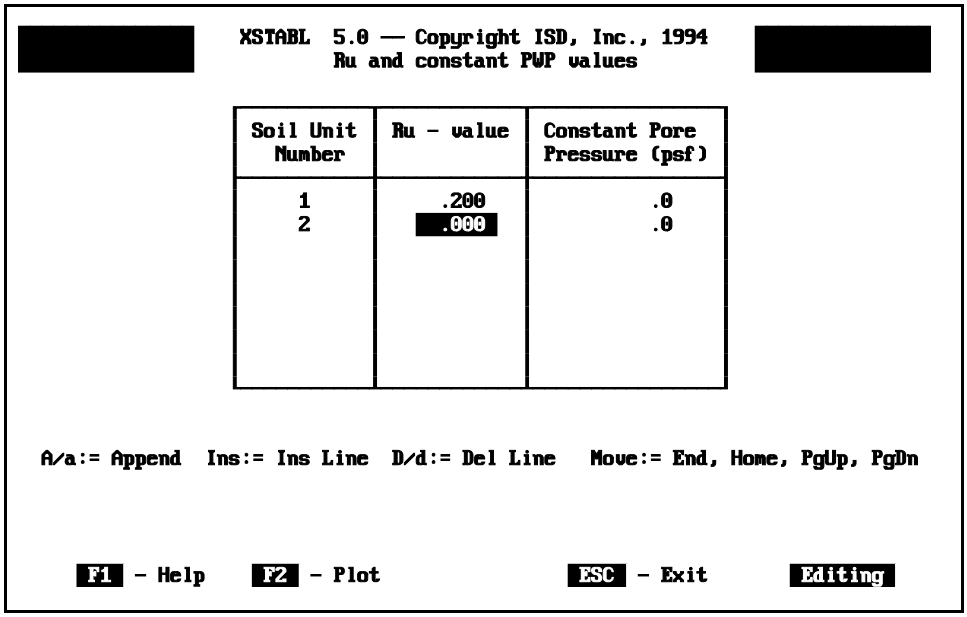

Fig. 3.28. Example data table for entering pore pressure coefficient r_u or a constant pore water pressure for a pre-defined soil unit

3.12 Pore Pressure Grid

This option is selected from the WATER category and allows the user to specify the pore water pressures in the slope at discrete locations. These pore pressures may be computed from:

(a) a flow net,

(b) a numerical solution (e.g. finite elements or finite differences), or

(c) a closed form solution for two dimensional flow in a slope.

This version of **XSTABL** allows the user to import directly the pore water pressure grid data from a previously created file that has been given a *.PWG extension. The ability to select from a list of valid filenames is provided via the F3 key. If you do not wish to import any data, a "n" response to the prompt will set the data table into an append mode for entering the the pore pressure data directly, as shown in Fig. 3.29. After data has been entered, pressing the **ESC** key terminates the automatic entry phase.

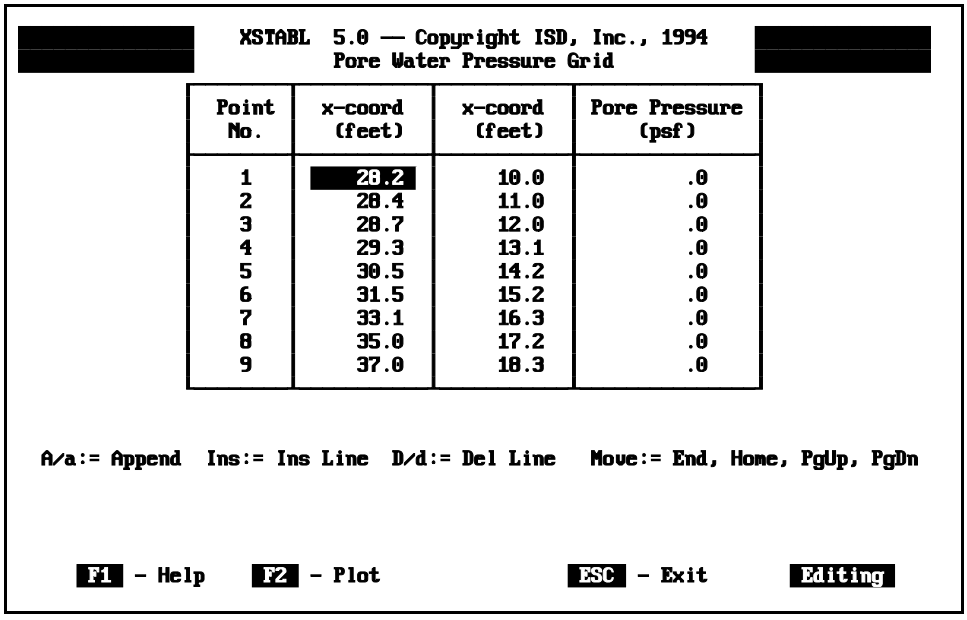
XSTABL 5.0 — Copyright ISD, Inc., 1994
Pore Water Pressure Grid
Point No.
x-coord (feet)
x-coord (feet)
Pore Pressure (psf)
1 28.2 10.0 .0
2 28.4 11.0 .0
3 28.7 12.0 .0
4 29.3 13.1 .0
5 30.5 14.2 .0
6 31.5 15.2 .0
7 33.1 16.3 .0
8 35.0 17.2 .0
9 37.0 18.3 .0
A/a:= Append Ins:= Ins Line D/d:= Del Line Move:= End, Home, PgUp, PgDn
F1 - Help
F2 - Plot
ESC - Exit
Editing

Fig. 3.29. Example data table for Pore Water Pressure Grid values

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Input data for pore pressure grid option consists of the x and y coordinates of the location where the pore water pressure (in psf or kPa) is known. **XSTABL** can accommodate up to 200 discrete points. As the pore water pressure at the base of each slice is calculated using an interpolation scheme, the user should recognize that this estimate will only be "as-good" as the input values. Thus it is important that the pore pressure values be specified at adequate locations within the region where potential failure surfaces are to be generated. **Preferably, the pore pressure grid should provide coverage of the entire slope**. *Please note that the slope analysis will terminate with an execution error if a pore water pressure grid and a water surface is specified for the slope.*

Pore Water Pressure Grid - Example

Figure 3.30 shows an embankment that has reached steady-state conditions with respect to the seepage of water from the reservoir. An approximate flow-net has been determined with the assumption that the embankment material has isotropic permeability.

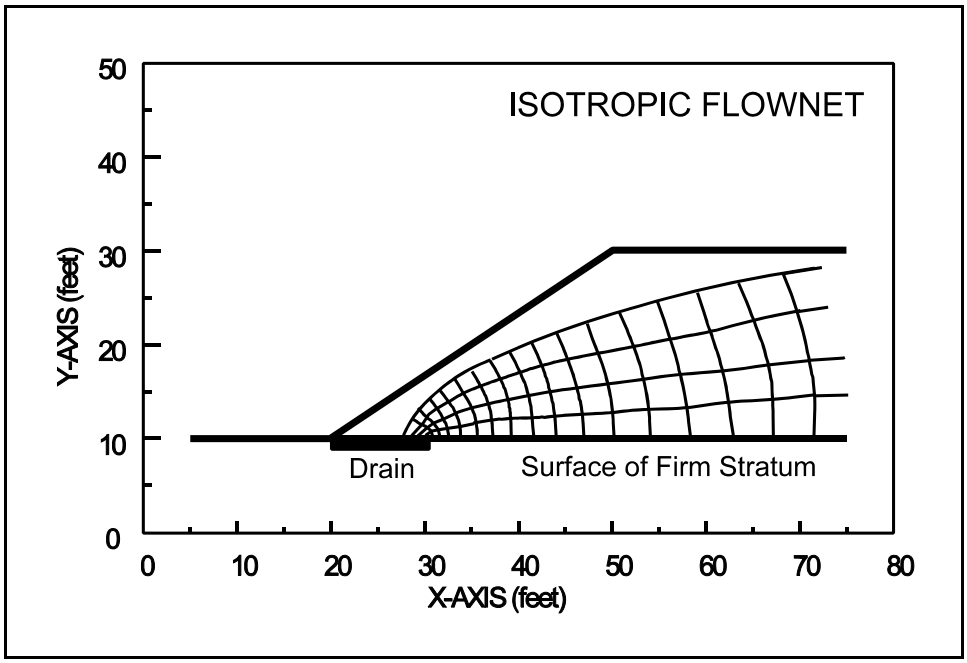

Fig. 3.30. Flow net for an example embankment (Lambe & Whitman, 1969)

From the flow-net, one can calculate the pore water pressures at locations within the embankment. For this example, the pore water pressures were determined at the intersection of all flow and equipotential lines. The intersections were used mainly for convenience. Any other points, perhaps on a rectangular grid, would also have been appropriate for this analysis.

The data file: **EX_5.IPT**, included as an example on the **XSTABL** disk, includes the numeric

values of these pore water pressures. In this example, 90 discrete points were selected for specifying the pore pressure. Fig. 3.30 shows the data table for the pore water pressure grid from the example file EX_5.IPT. The first 18 points in this example correspond to the phreatic surface where the pore water pressure is zero. Beyond point 18, positive pore water pressures are present as shown in the data table in Fig. 3.30.

3.13 Earthquake Loads

Earthquake loads may be included in the analysis by selecting the "earthquake" option from the "LOADS/LIMITS" category. The user is then prompted to type the values of the horizontal and vertical seismic coefficients into the simple data table shown in Fig. 3.31.

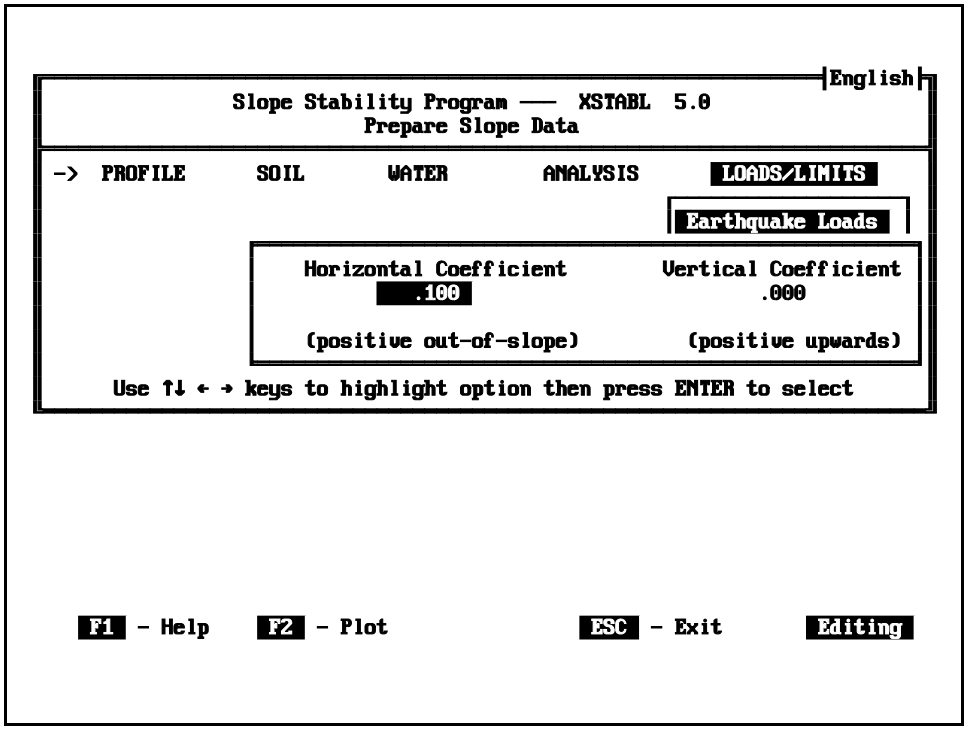

Fig. 3.31. Example data table for specifying earthquake loads

These coefficients are used to perform a pseudo-static analysis to simulate the effects of an earthquake. Positive horizontal and vertical directions for these coefficients indicate a pseudo-static earthquake force that is directed leftwards and upwards, respectively.

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3.14 Surcharge Loads

Uniformly distributed boundary loads, applied at the ground surface, may be specified using the appropriate option available under the "LOADS/LIMITS" category. Data defining the location, intensity, and inclination of up to ten different boundary loads may be specified into a data table of the type shown in Fig. 3.32.

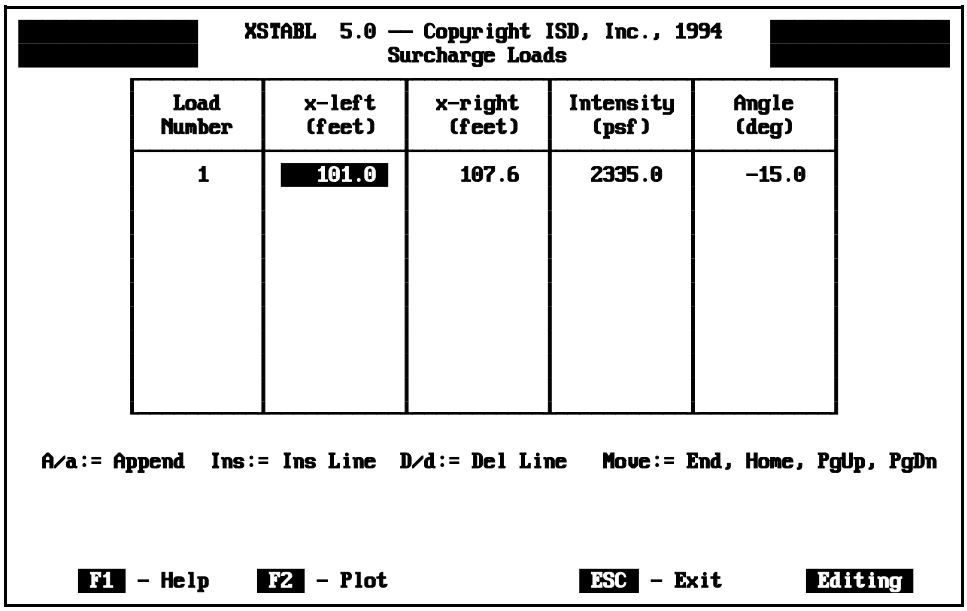

Fig. 3.32. Data table for specifying surcharge loads

The limiting equilibrium model used for the analysis treats each boundary load as a "strip" load of infinite length. The extent of the loaded area is defined by the x coordinates of the left and right side of the range as shown in Fig. 3.33. The specified intensity (in pounds per square foot, psf, or kilo Pascals, kPa) should be in terms of the load acting on a horizontal projection of the ground surface rather than the true length of the ground surface.

The inclination of the load is specified with respect to the ***vertical axis***, taking the counterclockwise angular direction as positive. The specified ranges for the loads must not overlap and should be ordered in a left-to-right sequence for either left *or* right facing slopes.

For slope analysis, these loads exert an additional force at the base of the slice. However, please note that these forces do not attenuate with depth. If the user wishes to simulate wheel-loads, for example, an appropriate surface surcharge that is less than the original force will have to be specified in order to simulate the reduction of the surface loads as a functions of depth. Since this reduction is a function of the (x, y) coordinates, this type of specification is limited to the analysis of individual failure surfaces only.

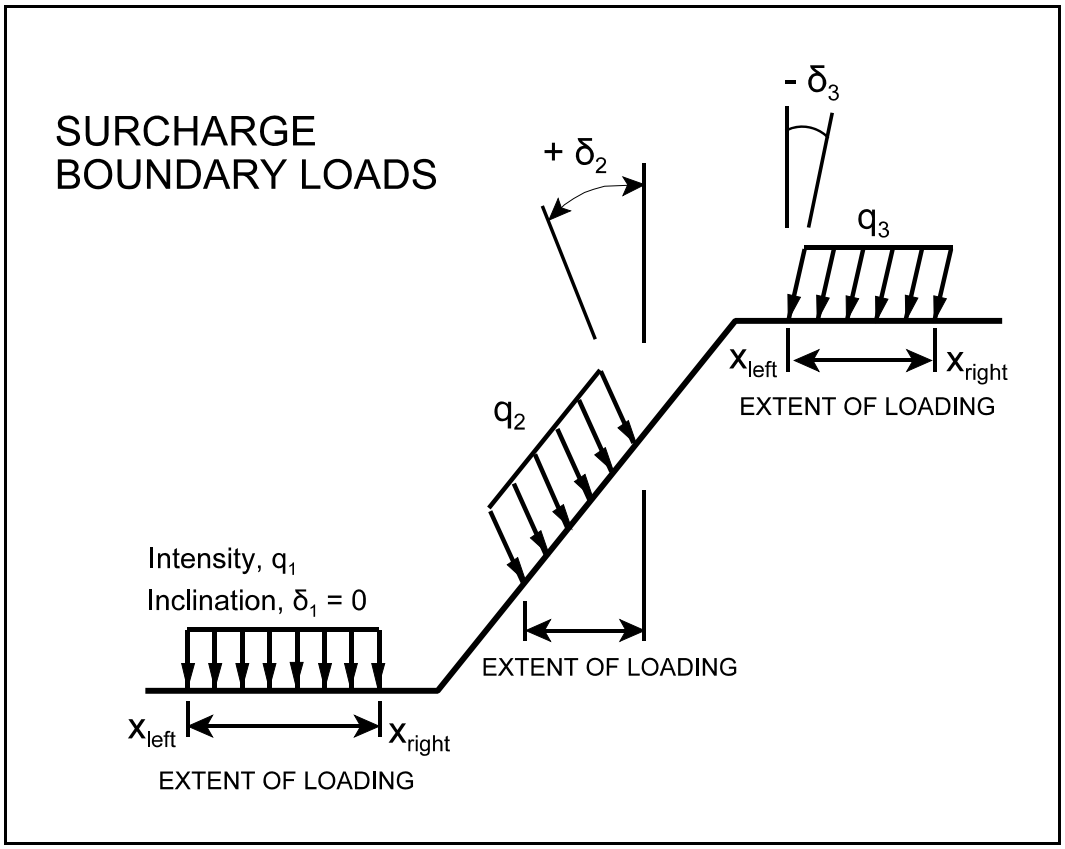

Fig. 3.33. Definition of terms for specifying surcharge loads

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3.15 Limiting Boundaries

If during the search for the most critical surface, the user wants to restrict surface generation to a specific region of the slope, the "Lower" and/or "Upper" limits may be selected from the list of options available under the "LOADS/LIMITS" category. These limiting boundaries provide a measure of control for the generation of multiple surfaces during the search for the most critical failure surface. Since generated surfaces may not pass through a limiting boundary, surfaces are "forced" within specific regions of the slope.

These limiting boundaries consist of a series of interconnected segments that are input in the same manner as the data for the *surface boundary*. There are two types of limiting boundaries, lower and upper, that may be used to confine the surface generation to a specific region.

Lower Limiting Boundary

The lower boundary effectively deflects the generated surfaces upwards, thus preventing passage of surfaces below this boundary, as shown in Fig. 3.34(a). The use of a lower limiting boundary provides an ideal method for delineating an undulating, relatively hard-layer within the slope, since the critical surface is unlikely to penetrate such a hard-layer.

Upper Limiting Boundary

An upper boundary achieves the opposite effect compared to the lower boundary. In this case, generated surfaces are forced to deflect downwards. Such a limiting boundary is useful for "forcing" surfaces deeper into the slope or around zones that contain relatively stronger materials. For example, in analyzing the external stability of a reinforced earth wall, an upper limiting boundary can be specified around the perimeter of the "reinforced" soil area, as shown in Fig. 3.34(b).

These boundaries may be used with all the surface generating methods except the RANKINE option for block surfaces. Such a boundary is not consistent with the RANKINE option which assumes that the failure segment orientation is fixed by the search box location and the φ value of the soil unit. If a limiting boundary is specified for the RANKINE option, it is ignored by the program and an informational message will be inserted into the output. In specifying these limiting boundaries, the user should ensure that the surface generation options are not overly restricted to a very narrow region. If such a restrictive specification is noticed during program operation, the user will be informed by an appropriate error message.

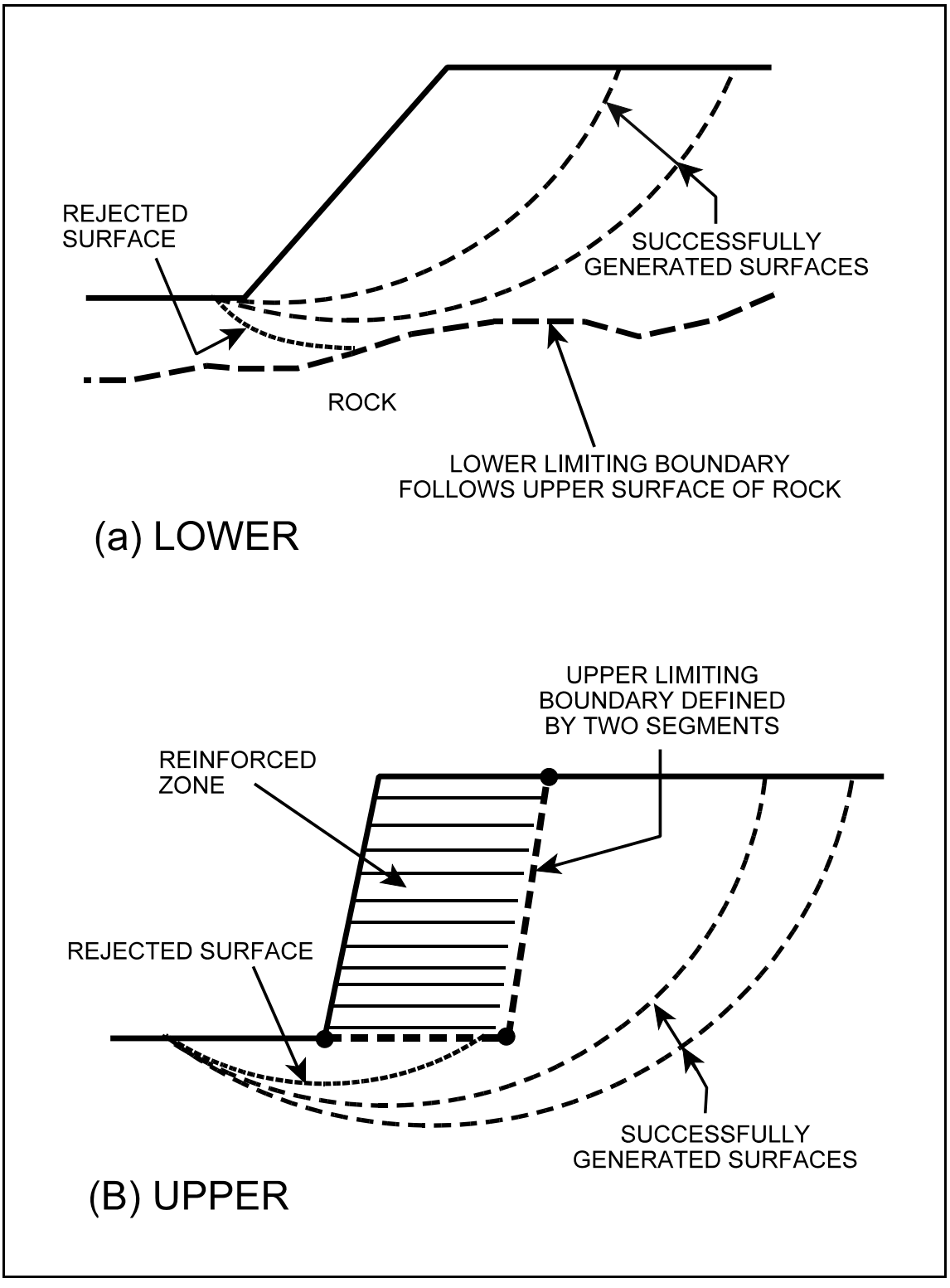

Fig. 3.34. Examples of lower and upper limiting boundaries

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CHAPTER 4

4.0 METHODS OF ANALYSIS

The **XSTABL** program allows the user to either search for a critical surface or determine the factor of safety for a specified individual failure surface. The simplified **Bishop** or **Janbu** methods of analysis are used by the program for all search analyses used to identify the critical surface with the lowest factor of safety. The rigorous methods, such as the **GLE** or **Janbu's GPS** methods, may be subsequently used to further study the stability of any single surface. The search and analysis options are chosen from the five selections available under the "ANALYSIS" category, as shown in Fig. 4.1, below.

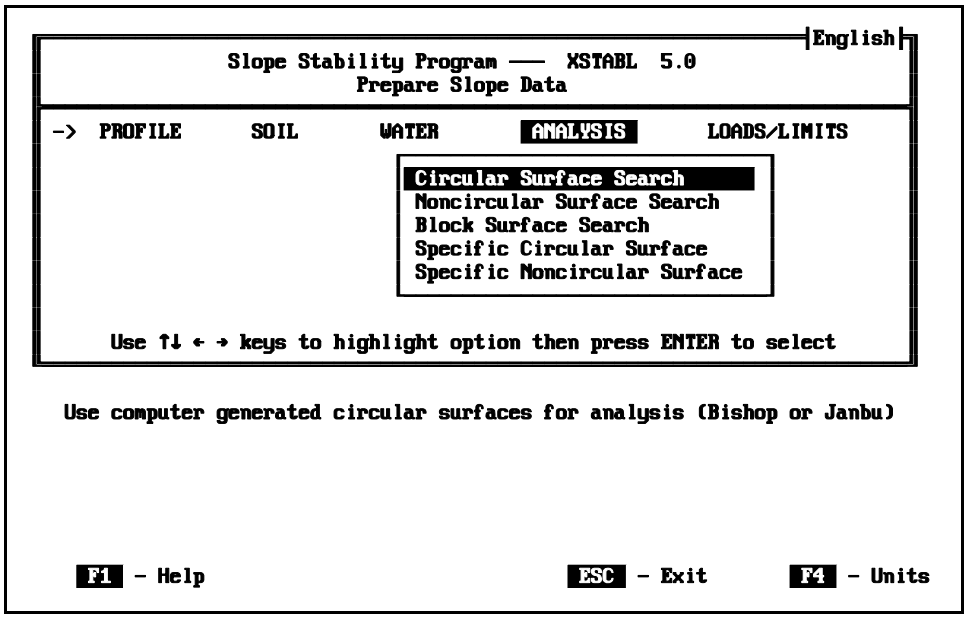

Fig. 4.1. Options available for slope analysis

4.1 Analysis of Right Facing Slopes

You may input the slope geometry in any convenient direction for analysis. Typically, slope data is entered for left-facing slopes, but if a right-facing slope is to be analyzed, please comply with the following requirements:

UPPER/LOWER ANGULAR LIMITS: These are based on rotation around the negative x-axis, with clockwise direction being taken as positive. With this convention, the default lower-limit will still be -45°.

SEARCH-BOXES: These search boxes MUST be ordered such that they sequentially progress from the PASSIVE zone (near the toe) to the ACTIVE zone (at the crest) of the slope. Thus for right-facing slopes, these boxes **must** be specified in a right to left direction, whereas for the left facing slopes, the required sequence is in a left to right direction.

SPECIFIC, SINGLE SURFACES: These surfaces must be input such that coordinate points follow a sequential order progressing from the toe of the slope to the crest. Thus the sequential x-coordinates will increase for a left-facing surface, while the x-coordinates will decrease for a right-facing slope.

If the above conditions are not violated, the program will analyze a right-facing slope in the same manner as left-facing slopes.

XSTABL *flips* the geometry of the input right-facing slope such that it is internally analyzed as a *left-facing* slope. This modification allows the error checking algorithms, developed for left-facing slopes, to be used for right-facing slopes as well. Once the surface has been analyzed, its geometry is flipped back to its original configuration.

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4.2 Search for Critical Surface

The search for the critical surface requires the generation of many potential failure surfaces that can be either circular, irregular or block shaped. The surface with the lowest factor of safety may then be pronounced as the "most" critical surface. The number of surfaces examined and the shape of the surface are specified by the user. **XSTABL** employs STABL's unique method of surface generation to examine and analyze an unlimited number of surfaces within user-defined regions of the slope.

Each surface is developed by using computer generated random numbers. Generally, the random number value affects the inclination of the failure surface segments for the circular and noncircular surface generation options. For the block surface generation, the random numbers are used to select points within the user-defined search boxes.

REMARK ABOUT RANDOM NUMBER SEQUENCE

The random number sequence, used by **XSTABL**, consists of a fixed series of values that permit the user to duplicate previous analyses. Thus if the user requests the generation of 200 circular surfaces, the same, identical 200 surfaces will be generated in all instances, providing the parameters are not altered. However, if the user wishes to generate 200 different surfaces, at least one of the following surface generation parameters must be changed:

1. segment length,
2. initiation range,
3. number of initiation points.

For a more thorough review of this methodology, the user should refer to the report by Sharma (1991) or the paper: "*Random Surface Generation in Stability Analysis*", by Siegel, R.A., Kovacs, W.D. and Lovell, C.W., ASCE, GT-7, July, 1981, pp. 996-1002.

4.3 Circular Surfaces

Circular surfaces may be readily generated and their factor of safety analyzed by the simplified Bishop or Janbu methods. Ten values are required for this data table, as shown in Fig. 4.2.

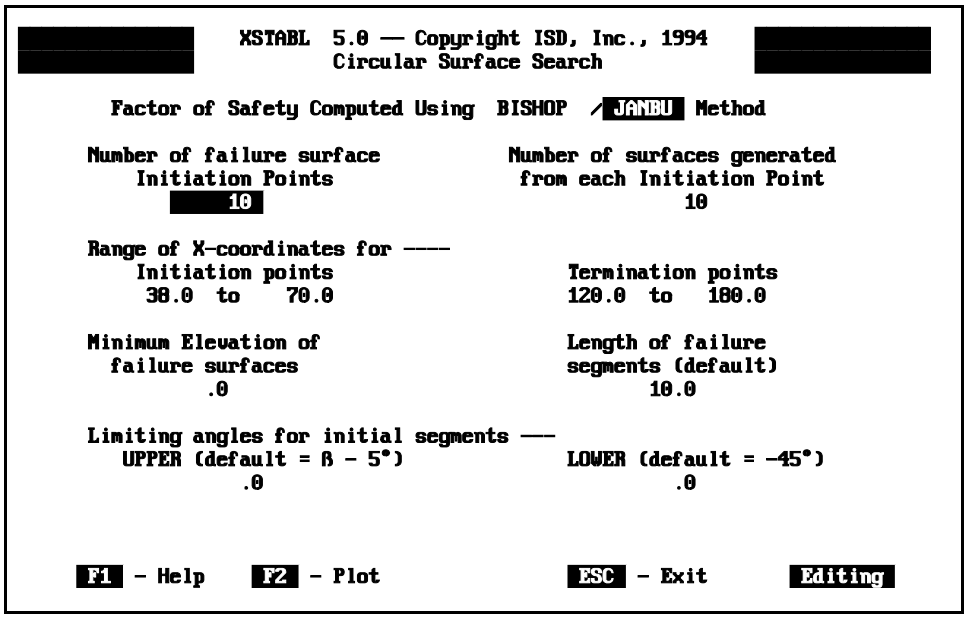

Fig. 4.2. Data table for a circular surface search (file EX_2.IPT)

Upon being presented this data table, the user is required to select the method for calculating the factor of safety, i.e. Bishop or Janbu. This option is simply selected by highlighting the appropriate label using the left/right cursor keys and then pressing the **ENTER** key. After this selection, the remaining data can be readily entered into the data table. The terms used to describe this input data are illustrated for a typical slope in Fig. 4.3, and are discussed in detail below:

1. Number of initiation points -- these represent the points at which the first failure surface segment begins. These initiation points are equally spaced within the specified initiation range given in item 3, below. If only <u>one</u> initiation point is requested, it is placed at the x_{left} position of the initiation range.
2. Number of surfaces to be generated from each initiation point.

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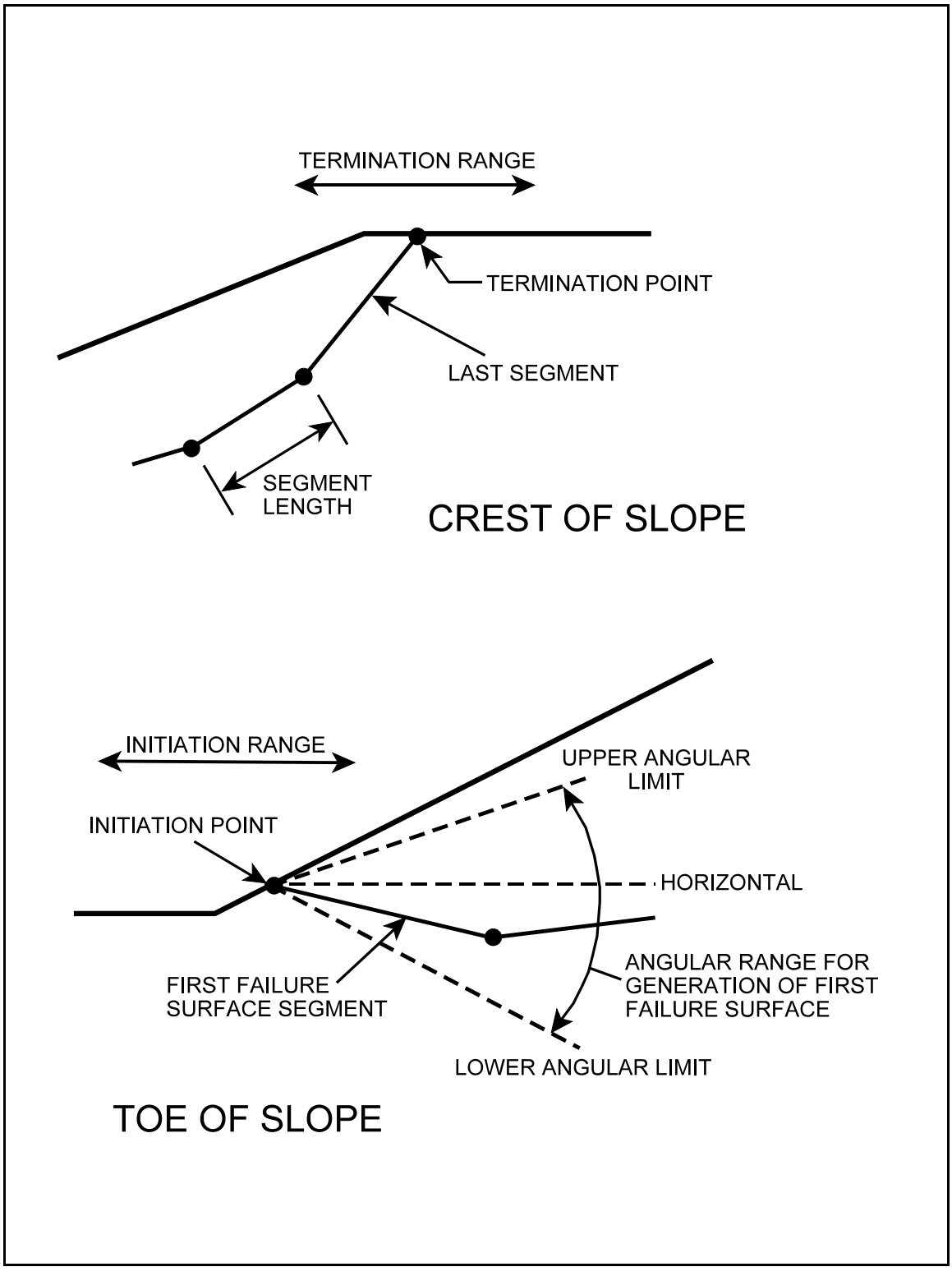

Fig. 4.3. Definition of parameters used for generating circular and noncircular surfaces

3, 4. x_{left} and x_{right} coordinates for the lateral range for the location of the initiation points.

5, 6. x_{left} and x_{right} coordinates for the lateral termination range where the last segment of the failure surface will exit at the ground surface.

7. Minimum elevation of surface development -- provides a horizontal limiting boundary for generated surfaces. This option prevents analysis of surfaces that project below this specified elevation, saving some CPU time. This may be used to simulate relatively hard layers of soil that are unlikely to accommodate a potential failure surface.

8. Segment Length -- defines the length of the segments used to simulate the failure surface. Ideally this length should be about 0.1H for circular surfaces and about 0.3H for noncircular surfaces, where H is the maximum height of the slope.

Please note that a default segment length is selected by XSTABL if the user enters a segment length of 0.0 (zero). This feature allows the user to quickly analyze a slope without having to manually determine a reasonable value for the segment length. However, there may be some instances where the default value may lead to an error. In such cases, the user will have to enter a value manually to complete the slope analysis successfully.

Although a small segment length can be expected to model a circular shape more effectively, the failure surface may be defined by a maximum of 99 segments only (or 100 x, y coordinates). Also, smaller segments will increase the number of discretized slices, thus requiring more CPU time with only a small improvement in accuracy.

9. Upper Angular Limit -- restricts the orientation of the first failure surface segment below this angle. The angle is always specified with respect to the horizontal, with the counterclockwise direction being positive.

If an upper angular limit is defined as 0.0 °, XSTABL automatically assigns a default upper angular limit equal to (ß - 5 °), where ß is the angle of the slope at the failure surface initiation point. This default option is useful in cases where the slope within the initiation range has a varying degree of steepness.

Please note that if a **horizontal** upper angular limit is required, a **non-zero** value must be specified to prevent **XSTABL** from using the default angular limit. *For such cases, a value of 0.01 ° is recommended.*

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10. Lower Angular Limit -- provides a lower limit for the generation of the first failure surface segment. The angle is always specified with respect to the horizontal, with the counterclockwise direction being positive.

If a lower angular limit is defined as 0.0 °, XSTABL automatically assigns a default lower angular limit equal to -45 °. Values beyond -45° are generally *not* recommended !

Similar to note 7, above, please note that if a **horizontal** lower angular limit is required, a **non-zero** value must be specified to prevent **XSTABL** from using the default angular limit. *For such cases, a value of 0.01 ° is recommended.*

4.4 Noncircular Surfaces

Noncircular or irregular shaped surfaces, may be analyzed using the simplified Janbu method of analysis. The data required for this option is identical to that required for the circular surface search, discussed above.

REMARK ON SEGMENT LENGTHS

The algorithms for generating noncircular surfaces are very sensitive to the specified segment length. If the segment length is "too" small, it is possible that kinematically inadmissible surfaces (i.e. very unusual and irregular surfaces which cannot possible fail due to their "kinkiness" !) may be generated and subsequently analyzed. These erroneous surfaces will contaminate the search for the critical surface and may give the user a false impression about the minimum factor of safety. *The most effective approach that will minimize this effect is to use the largest feasible segment length.* This should generally be about 0.3H, where H is the maximum slope height.

Please note that **XSTABL** will select a similar length if a **default** segment length is requested by the user.

4.5 Block Surfaces

Block shaped surfaces provide a means to concentrate the surface generation within a confined zone that may represent a potentially "weak" layer. This option utilizes user-specified **search boxes** for generating the central portion of a failure surface and then offers two methods for generating the passive and active portions to complete the block surface as shown on Fig. 4.4.

The central portion of the block surface is generated by connecting randomly selected points within each of the boxes. The passive and active portions are then completed by using one of the following methods :

(a) **RANKINE** -- generates the passive and active portions of the failure surface at the following fixed angles (measured from the vertical) in accordance with the Rankine approach:

Passive --- $(45 + \varphi/2)$
Active --- $(45 - \varphi/2)$

The angle of each failure segment within the passive and active blocks will be determined by the φ-value of the surrounding soil unit.

(b) **BLOCK** -- generates the passive and active portions of the block surface using irregularly oriented segments. This approach for the end-sections is similar to the methods used to generate irregular shaped surfaces. So the user should pay special attention to the selection of an appropriate segment length, as discussed earlier for the noncircular surfaces. The user can request **XSTABL** to use a default segment length by specifying a segment length of zero in the data table.

In general, the **RANKINE** method is recommended, due to its consistency, for use in developing block-shaped trial failure surfaces. Typical data for block-shaped surface generation option is presented in the data table shown in Fig. 4.5.

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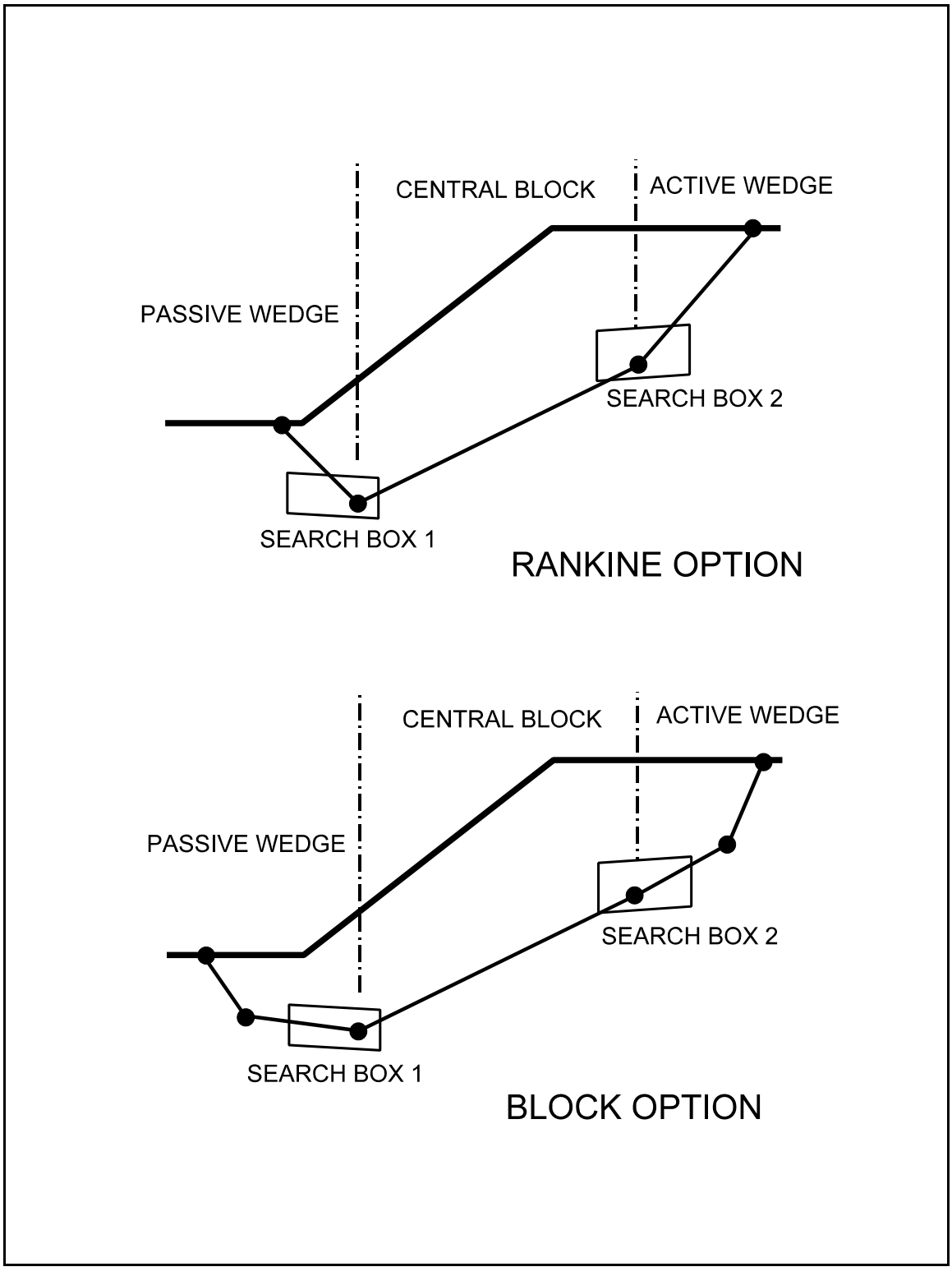

Fig. 4.4. Passive and active wedge differences for the RANKINE and BLOCK options

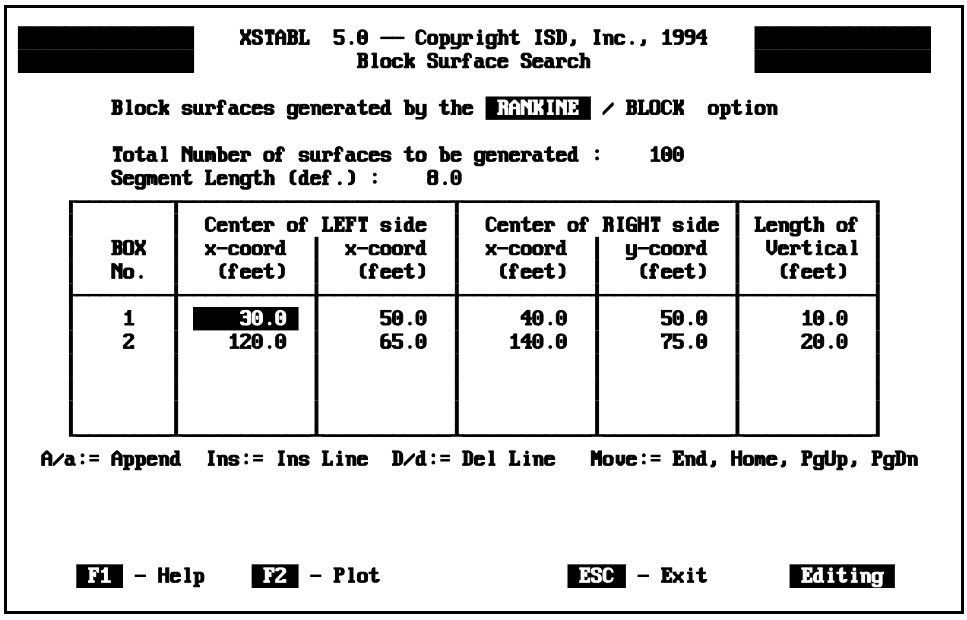
XSTABL 5.0 — Copyright ISD, Inc., 1994
Block Surface Search
Block surfaces generated by the RANKINE / BLOCK option
Total Number of surfaces to be generated : 100
Segment Length (def.) : 8.0
BOX No.
Center of LEFT side x-coord (feet)
Center of LEFT side y-coord (feet)
Center of RIGHT side x-coord (feet)
Center of RIGHT side y-coord (feet)
Length of Vertical (feet)
1 30.0 50.0 40.0 50.0 10.0
2 120.0 65.0 140.0 75.0 20.0
A/a:= Append Ins:= Ins Line D/d:= Del Line Move:= End, Home, PgUp, PgDn
F1 - Help
F2 - Plot
ESC - Exit
Editing

Fig. 4.5. Data table for block surface search (file EX_3.IPT)

After selecting the type of analysis (i.e. RANKINE or BLOCK), and specifying the total number of surfaces to be examined and the segment length, the following data for up to 10 search boxes is entered into the table:

1. x, y coordinates at the center of the left vertical side of the specified search box,
2. x, y coordinates at the center of the right vertical side of the specified search box,
3. Length of the vertical side of search box.

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The above data will generate parallelogram shaped search boxes with vertical sides as shown in Fig. 4.4. However, the user may manipulate the search box parameters to specify the following non-parallelogram shaped zones:

(a) Point locations — if $x_{left} = x_{right}$, $y_{left} = y_{right}$ and the length of the vertical side is specified as zero,

(b) Horizontal Line — if length of vertical side is specified as zero, and $x_{left} \neq x_{right}$, $y_{left} = y_{right}$,

(c) Sloping Line —— if length of vertical side is specified as zero, and $x_{left} \neq x_{right}$, $y_{left} \neq y_{right}$,

(d) Vertical Line —— if vertical side > zero, and $x_{left} = x_{right}$ and $y_{left} = y_{right}$.

A **default segment** length may be requested by specifying the length as 0.0 (zero). In this case, **XSTABL** will select a segment length of 0.2H, where H is the height of the slope.

4.6 Analysis of Single Failure Surfaces

XSTABL provides numerous methods for quickly analyzing a single, user-specified surface. In this version, an input datafile containing the slope geometry and the specific failure surface is prepared without selecting a method of analysis. The method of analysis is selected during the analysis phase from the menu shown in Fig. 4.6. This approach allows the user to create a single input datafile, which can then be used to determine the factor of safety using one of the following procedures:

1. Spencer's method
2. General Limit Equilibrium (GLE) method
3. Janbu's General Procedure of Slices (GPS)
4. Force equilibrium methods (e.g. simplified Janbu)
5. Simplified Bishop method (circular surfaces only)

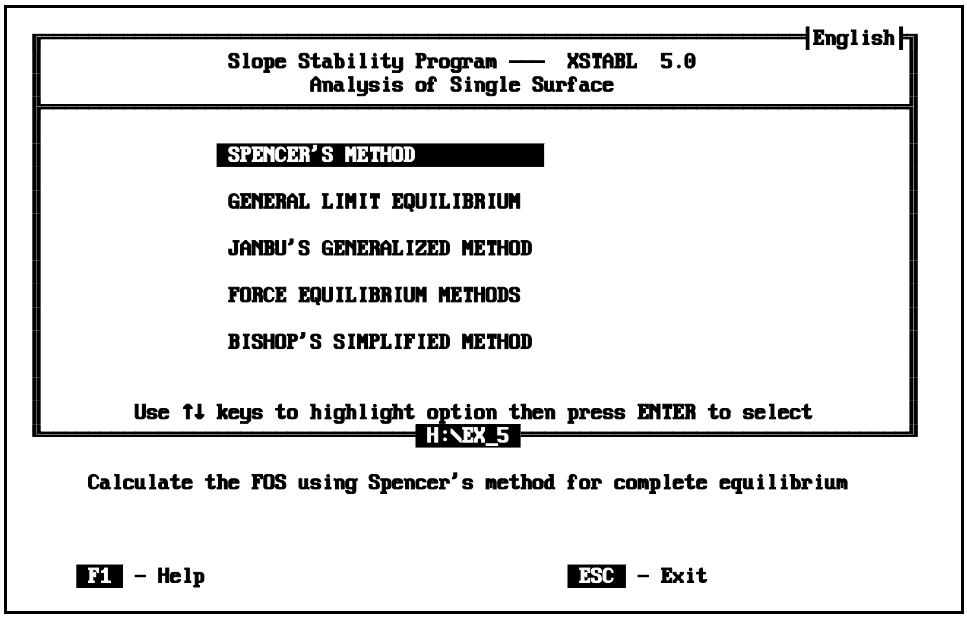
English
Slope Stability Program —— XSTABL 5.0
Analysis of Single Surface
SPENCER'S METHOD
GENERAL LIMIT EQUILIBRIUM
JANBU'S GENERALIZED METHOD
FORCE EQUILIBRIUM METHODS
BISHOP'S SIMPLIFIED METHOD
Use ↑↓ keys to highlight option then press ENTER to select
H:\EX_5
Calculate the FOS using Spencer's method for complete equilibrium
F1 - Help
ESC - Exit

Fig. 4.6. Options available for the analysis of a single specified surface

The main difference between the above methods is whether they satisfy force (in two directions) and moment equilibrium conditions. From the above list, procedures 1 and 2, satisfy all equilibrium conditions and procedure 4 just satisfies force equilibrium conditions. However, as the limit equilibrium solution is indeterminate, the rigorous procedures assume an interslice force angle distribution (see Fig. 4.7) to solve the limit equilibrium equations.

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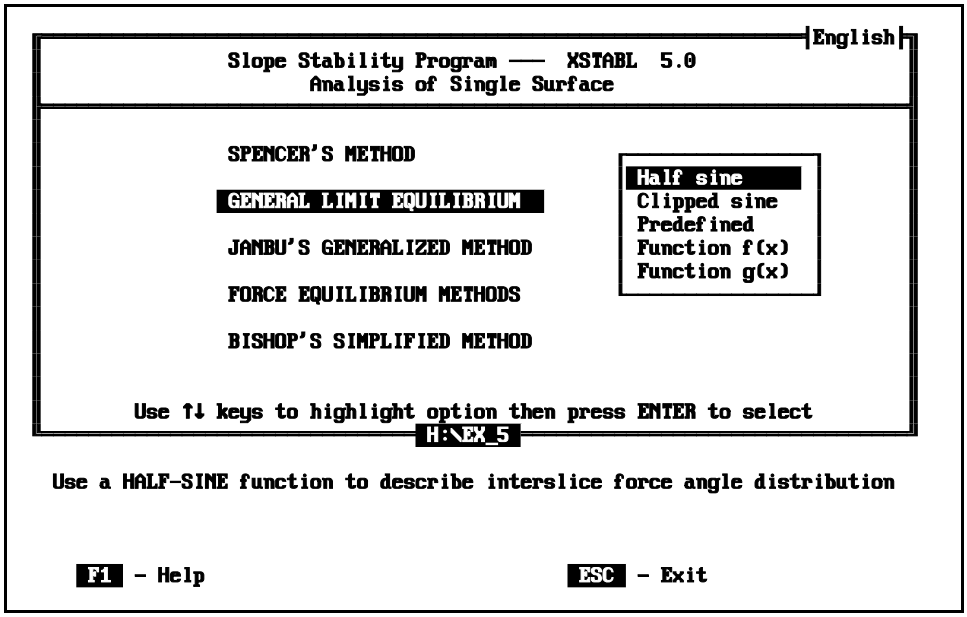

Fig. 4.7. Options available for the analysis of a single specified surface

Janbu's GPS procedure assumes a location of the thrust-line and satisfies force and moment equilibrium for all slices *except the last slice.* The simplified Bishop method satisfies overall moment equilibrium for all slices, but only considers force equilibrium conditions in one direction only.

Ideally, a method that satisfies complete equilibrium is more accurate than the methods that do not satisfy all equilibrium conditions. However, as an assumption regarding the interslice force angles is required, the calculated factor of safety (FOS) is not unique and its reasonableness must be assessed by the user. Occasionally, the rigorous methods cannot generate a FOS due to convergence problems and one must then resort to one of the force equilibrium methods, which are less susceptible to numerical difficulties. A complete description of the theory, assumptions and the algorithms used by **XSTABL** is given in Appendix D.

Data for a single failure surface may prepared depending on whether the surface is circular or noncircular. All analytical procedures may be used for a circular failure surface. *The simplified Bishop method has been formulated for circular surfaces only, and thus may not be used for noncircular surfaces.*

Circular Surfaces

Circular Surfaces are specified by four parameters that define the geometry of the circular arc with respect to the slope. Input data for this option is entered into the simple table shown in Fig. 4.8.

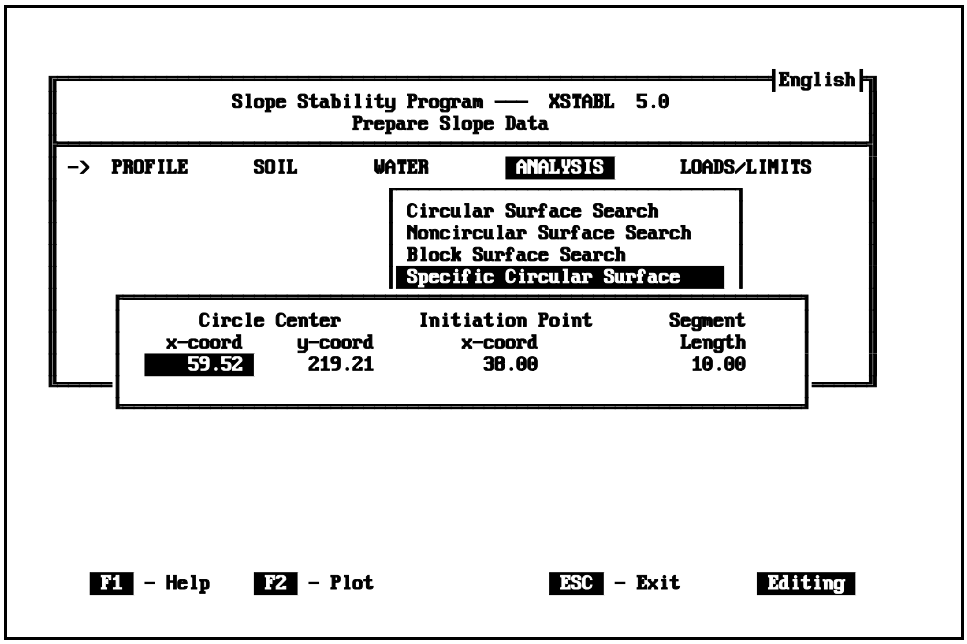

Fig. 4.8. Data table for a single Circular Surface

If data has not been previously entered for this option, the user is prompted for the following parameters :

(a) x and y coordinates of the circle center,

(b) x coordinate of the point along the ground surface where the surface initiates near the toe of the slope,

(c) segment length to be used in defining the circular shape.

Please note that a segment length greater than zero must be specified for this option as a default length is not available.

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Calculation of Circle Center

There may be cases where the user has collected data for a circular surface in the form of x and y coordinates. This surface can be analyzed readily using Janbu's method from the noncircular surface option, discussed in the next section. However, if the user wishes to analyze this surface using Bishop's method, the x and y coordinates of the center of the circular arc must be determined for use with the option mentioned above. In such cases, the following equations are recommended :

Let (x_0, y_0) = coordinates of the initiation point (near toe of slope)

(x_1, y_1) and (x_2, y_2) = coordinates along the failure surface at two points (preferably <u>not</u> two consecutive points)

Then if,

$$x_{01} = 0.5(x_0 + x_1) \quad \text{and} \quad y_{01} = 0.5(y_0 + y_1)$$

$$x_{12} = 0.5(x_1 + x_2) \quad \text{and} \quad y_{12} = 0.5(y_1 + y_2)$$

$$m_1 = \frac{x_1 - x_0}{y_0 - y_1} \quad \text{and} \quad m_2 = \frac{x_2 - x_1}{y_1 - y_2}$$

The coordinates of the center of the circle, (x_c , y_c), will be given by:

$$x_c = \frac{1}{m_1 - m_2} [- y_{01} + y_{12} + m_1 x_{01} - m_2 x_{12}]$$

$$y_c = y_{01} - m_1 x_{01} + m_1 x_c$$

and the radius, R, of the circular surface is given by the expression:

$$R^2 = (x_c - x_0)^2 + (y_c - y_0)^2$$

Now with the circle center coordinates known, the user can select an appropriate segment length to generate the same approximate arc for further analysis.

Noncircular Surfaces

Such surfaces are defined by a series of x and y coordinate points connected by straight line segments. The data table for this option consists simply of two columns where the x and y coordinates are entered by the user.

Upon selecting this option from the ANALYSIS category, the user will be asked if the data is to be read from an existing output file that contains the x, y coordinates of a failure surface. The ability to import these coordinates directly from a *.OPT file that contains the results of a search analysis allows the user to quickly check the factor of safety using one of the rigorous methods of analysis. If a search has been performed, the coordinates of up to 10 most critical surfaces may be written to the *.OPT file. So once the name of an approved *.OPT file is given, **XSTABL** reviews the file and reports the number of failure surface coordinates encountered. It will then request that the user select one of these surfaces. A typical example is shown in Fig. 4.9, where failure surface data for the first set of coordinates is about to be extracted from the EX_1.OPT file.

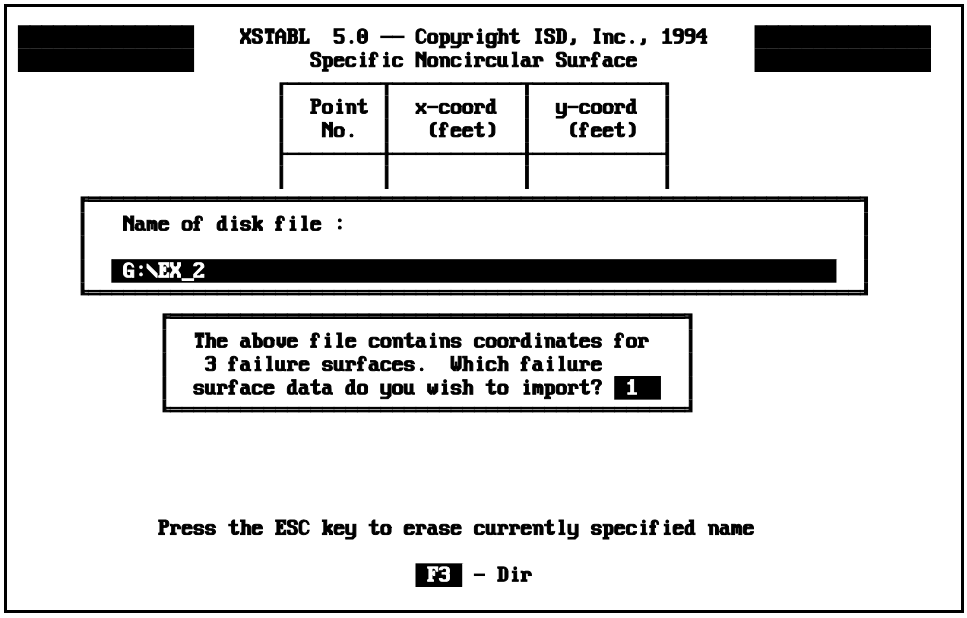
XSTABL 5.0 — Copyright ISD, Inc., 1994
Specific Noncircular Surface
Point No.
x-coord (feet)
y-coord (feet)
Name of disk file :
G:\EX_2
The above file contains coordinates for 3 failure surfaces. Which failure surface data do you wish to import? 1
Press the ESC key to erase currently specified name
F3 - Dir

Fig. 4.9. Prompt for option to read x, y coordinate data of a failure surface from a search generated *.OPT file

If you do not wish to read the data from an existing output file, a "n" response will place you into the append mode where the x, y coordinate data can be entered into the data table. Please note that up to 100 points may be used to define a noncircular failure surface.

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CHAPTER 5

5.0 STABILITY ANALYSIS

The slope analysis option is accessed directly from the "Main-Menu", discussed earlier. Upon selecting the "Stability Analysis" option, the user is presented with the "Slope Analysis" menu that prompts the user for the names of the input and output data files. An example session is shown in Fig. 5.1.

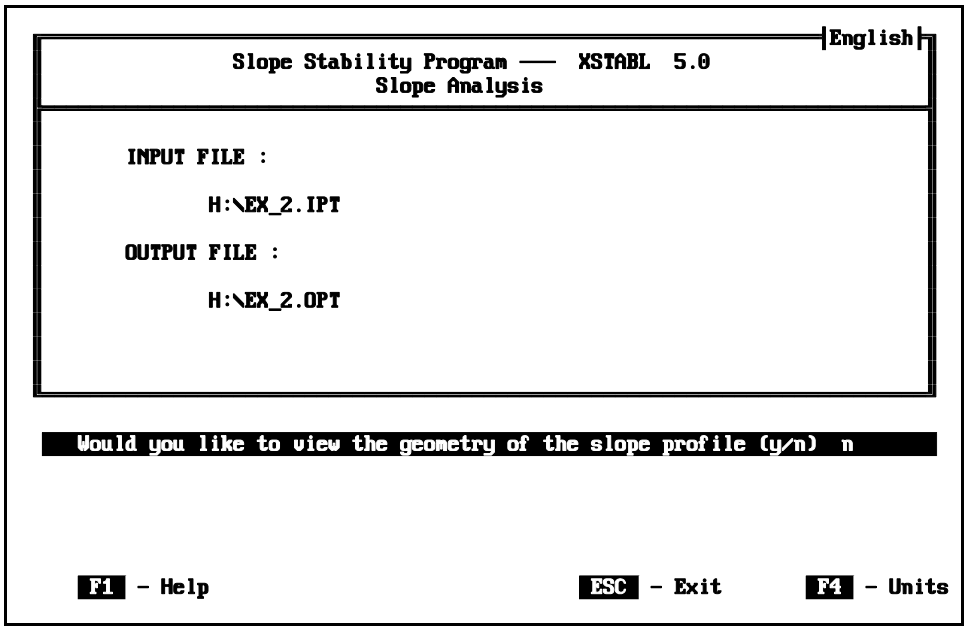

Fig. 5.1. Entering filenames for slope analysis

5.1 Filenames

The name of the input file will default to the last name that was used in the program. This minimizes the typing of filenames, especially those with long directory paths, and also reduces errors. At this prompt the user, again, has the option to press the **F3** key to access a directory listing. From such a listing, a file can be readily selected by highlighting the name and pressing **ENTER**.

The output filename will default to the "same" name as the input file for convenience. If the user wishes to select an alternative name (rather than the default provided) for the input or output files, the filename shown may be fully or partially erased and a new name typed. The user may erase the entire filename by pressing the **ESC** key, or alternatively use the backspace key to perform a partial edit.

At entry of each of the filenames, **XSTABL** will check for the following conditions :

1. Check existence of INPUT file -- user is warned if the file cannot be found in the requested directory or drive,
2. If the name of the OUTPUT file is the same as the name of an existing file -- in this case the user will be offered an option to "overwrite" the existing file with the new file, or to provide a different name,
3. If there is *less than 20 kb of space remaining* on the specified drive, the user is informed so that appropriate corrective measures may be taken before performing the stability analysis.

Fig. 5.1 shows a typical screen after the user has specified the input and output filenames (G:\EX_2.IPT and EX_2.OPT, in this case). If the filenames are correct, the input data is read and checked by **XSTABL**. If no obvious errors are detected, the user is offered an option to view the slope profile.

NOTE

If the user elects to save any of the three screen plots during the stability analysis and there is insufficient disk space available, incomplete plot files will be generated. The only way to prevent this from occurring is to ensure that at least 100 kb is **ALWAYS** available on the working drive.

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5.2 Plot of Slope Profile

If the user elects to view the slope profile, the screen is cleared and a plot of the slope geometry is drawn as shown in Fig. 5.2. If the RANKINE / BLOCK options are used, the search boxes will also be displayed in this plot. The user is then offered an opportunity to save the plot. If the user notices any errors from this plot, the analysis may be terminated by pressing the **ESC** key. Pressing the **ENTER** key will use the default, "N" (or "n"), for this option and the plot will *not* be saved during the slope analysis.

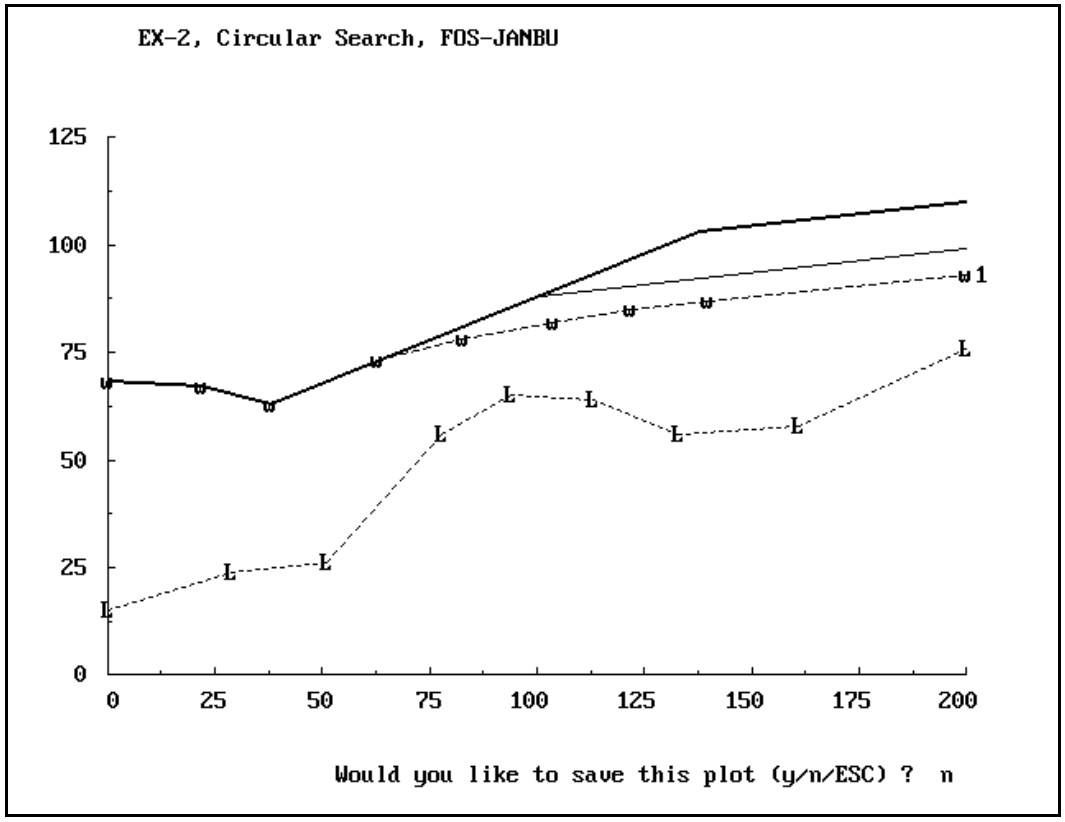

Fig. 5.2. Plot of slope geometry -- Stability Analysis using file EX_2.IPT

A "Y" (or "y") response indicates that the user wishes to save the plot to a diskfile. In this case a new prompt, as indicated in the lower part of Fig. 5.3, asks the user to select one of the three graphical formats that should be used to save the plot to a diskfile.

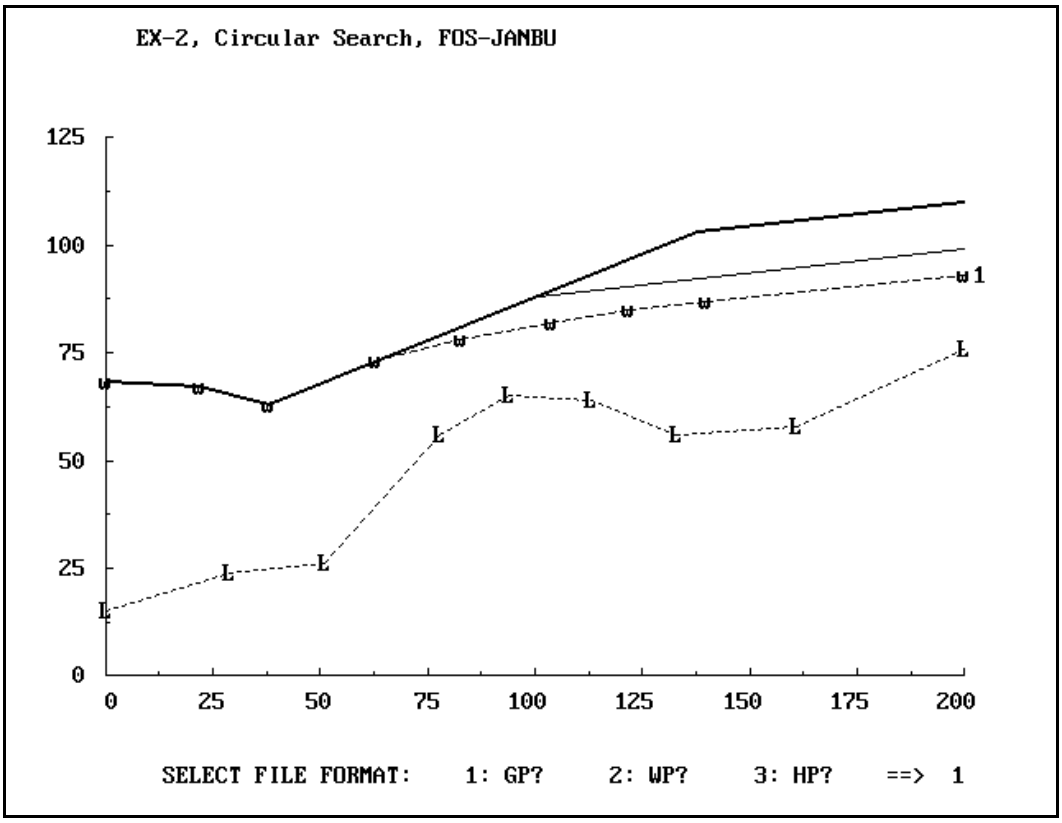

Fig. 5.3. Screen view showing request for either *.GP1, WP1 or HP1 graphical format for saving plot

The available graphic formats for saving a plot-file are:

(a) *Internal **XSTABL** format*: used for saving files that are to be printed directly using the **XSTABL** software. Please note that files saved in this format cannot be imported into other third party software.

(b) *WordPerfect Graphics format (WPG):* This is the standard graphics format that is used by WordPerfect products for importing/exporting graphical images. An **XSTABL** plot saved in this format can be imported into the WordPerfect wordprocessor, or the drawing programs: WordPerfect Presentations 2.0 or DrawPerfect. This graphical format is also supported by other desktop publishing or graphical/charting software.

(c) *Hewlett Packard Graphical Language (HPGL)*: this format creates an ASCII file written in compliance with the HPGL language that has been developed to support HP plotters. Although these files cannot be plotted directly, they can be imported into third-part software applications such as word-processing, desktop publishing or drawing (e.g. AUTOCAD) applications.

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The saved plot file will have the same name as the output filename, but with the following extensions:

(a) **XSTABL** format: *.GP1, *.GP2, *.GP3 and *.GP4,

(b) WPG format: *.WP1, *.WP2, *.WP3, and *.WP4,

(c) HPGL format: *.HP1, *.HP2, *.HP3. and *.HP4.

The last number in the above filename extension identifies the type of plot saved, i.e.:

slope geometry —— **1**

surface generation —— **2**

critical surfaces —— **3**

Special plot for single surface analysis —— **4**

Please note that the HPGL files are likely to be *considerably* larger, by a factor of ***two or three***, than the plot files saved in one of the other two formats. Before electing to use this format, the user should check on the availability of adequate disk space.

5.3 Plot of Generated Surfaces

Upon electing to continue with the stability analysis, the screen clears and the user is presented with several options concerning the viewing and/or plotting of **ALL** surfaces generated by the program. The available options are the same as those shown in Fig. 5.4, and discussed below.

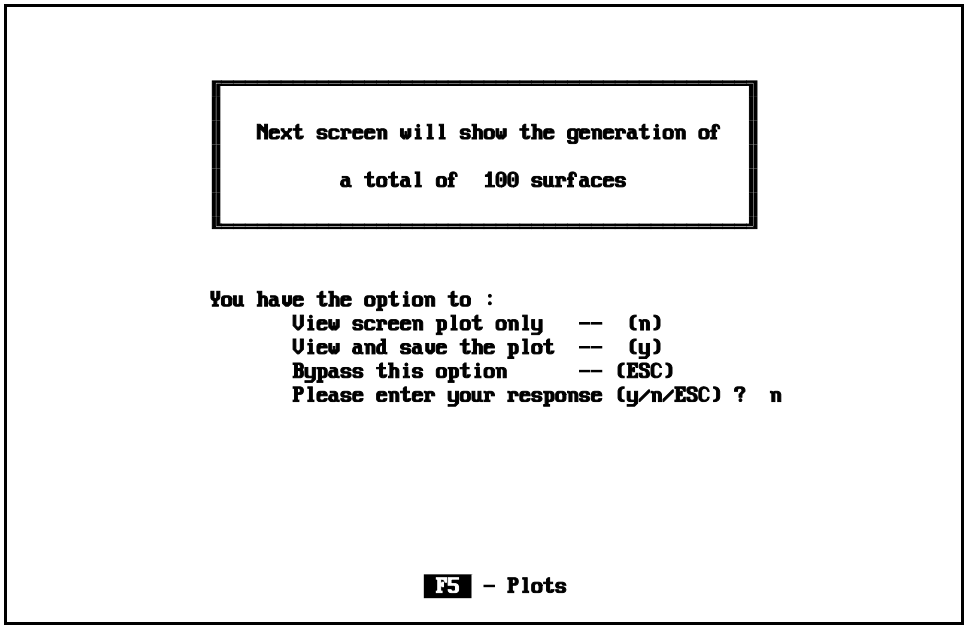
Next screen will show the generation of
a total of 100 surfaces
You have the option to :
View screen plot only -- (n)
View and save the plot -- (y)
Bypass this option -- (ESC)
Please enter your response (y/n/ESC) ? n
F5 - Plots

Fig. 5.4. Options available for viewing progress of stability analysis

For a search analysis, **XSTABL** can :

1. For noncircular failure surfaces, write the x, y coordinates of the 10 most critical surfaces to the output file. For a circular surface search, only the x, y coordinates for the most critical surface are written to the *.OPT file;
2. Display the ten most critical surfaces on-screen;
3. Display the ten most critical surfaces to a saved hardcopy plot-file.

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The above limits of 10 surfaces for any of the three conditions may be changed from this menu via the **F5** key. If the **F5** key is pressed, the screen shown in Fig. 5.5 is displayed and the user can change the default values. Once changed, these values will remain the default values for all subsequent sessions as these numbers are written to the SETUP1.STB configuration file. After making the necessary changes, press the **ESC** key will register the new values and return the user to screen shown earlier in Fig. 5.4.

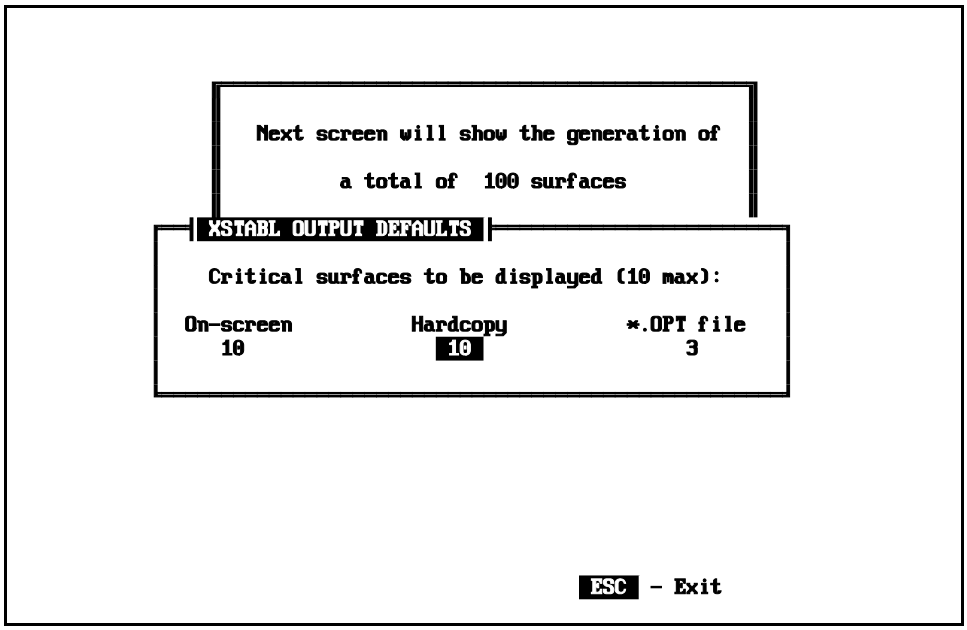

Fig. 5.5. Changing the default number of surfaces displayed on-screen, included in the hardcopy plot and written to the *.OPT file

Depending on the option selected from the screen shown in Fig. 5.4, the following sequence will be available:

View screen plot only : should be selected if the user would like to see a display of ALL the surfaces that are generated and analyzed by **XSTABL**. Please note that these surfaces are difficult to view after about the first twenty. This option is set as the default option and thus pressing **ENTER** will allow the user to view the screen plot, as shown in Fig. 5.6.

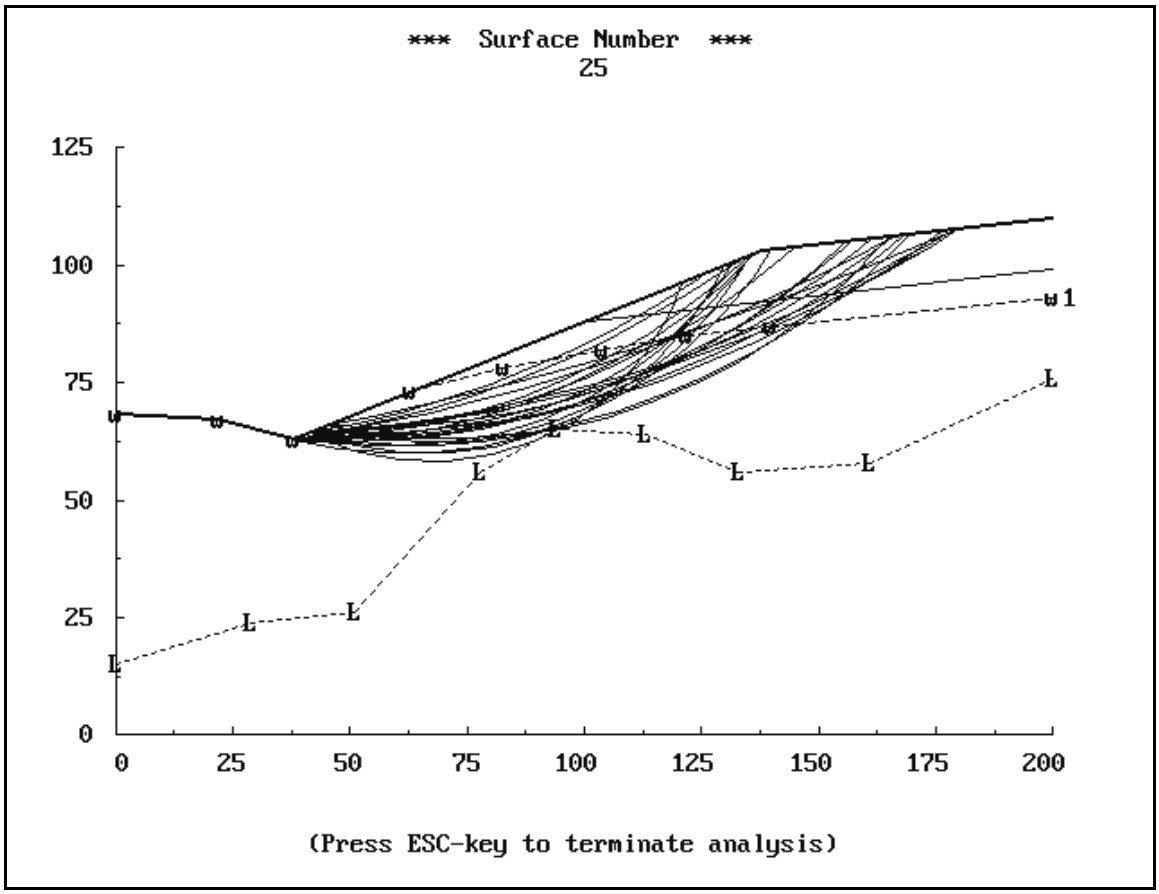

Fig. 5.6. View of screen after the generation and analysis of 25 surfaces (file EX_2.IPT)

View and save the plot : allows the user to view the plot on the screen and **SAVE** it for later printing. This option is selected by pressing the "y" (or "Y") key and will be followed by a request to select the desired graphical format. This plot is saved with the filename extension, *.GP2, *.WP2 or *.HP2, according to the format selected. An example of the printed plot of 100 surfaces is included in the section titled: "**Hardcopy Plots**".

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Bypass this option : permits the user to save some CPU time and omit the screen plot completely. This option is selected by pressing the **ESC** key. With this option, the screen will clear and a counter will display the status of the analysis and surface generation. Fig. 5.7 shows such a screen where the first 25 surfaces have been successfully generated and analyzed out of a total of 100 surfaces.

Please note that with the selection of this option, a hardcopy plot of the generated and analyzed surfaces cannot be saved for printing later.

During the surface generation and analysis phase, the user may cancel the analysis at any time by pressing the **ESC** key. The computations will immediately stop and be followed by a summary of up to ten critical surfaces, providing *at least ten surfaces* were generated and analyzed prior to termination. The output file will be created normally, except a message concerning this premature termination will be inserted into the text.

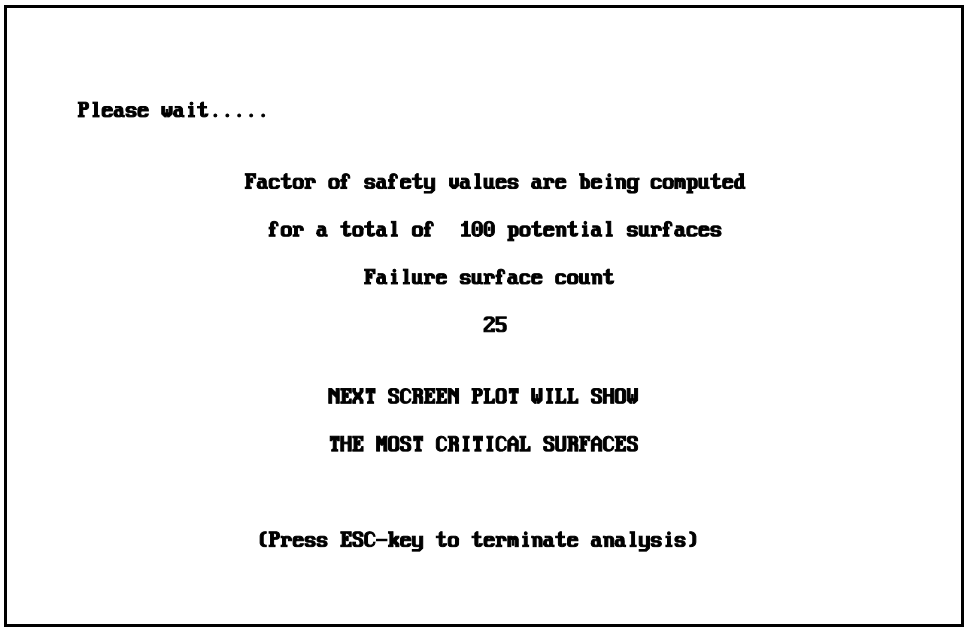
Please wait.....
Factor of safety values are being computed
for a total of 100 potential surfaces
Failure surface count
25
NEXT SCREEN PLOT WILL SHOW
THE MOST CRITICAL SURFACES
(Press ESC-key to terminate analysis)

Fig. 5.7. Screen showing progress of analysis if user wishes not to view the on-screen surface generation

This feature is useful for cases where the user requests several hundred surfaces for analysis but wishes to stop the program to change some parameters before continuing.

5.4 Negative Effective Stresses

The limit equilibrium method that has been implemented via the "simplified" procedures suggested by Bishop and Janbu can sometimes lead to numerical difficulties that are manifested by **negative** normal effective stresses calculated along the failure surface. Negative effective stresses are usually encountered for cases that involve:

(a) ***high*** pore water pressures,

(b) a combination of thin slices with a low self-weight and a high "c-value", and

(3) ***steep*** slice-base angles.

Most of these problems are associated with the indeterminacy of the limit equilibrium analysis and the failure to adequately satisfy the conditions for complete static equilibrium. These problems are discussed in greater detail in Appendix D.

If negative stresses are encountered during a search, the analysis is temporarily suspended and the user is cautioned on-screen, as shown in Fig. 5.8.

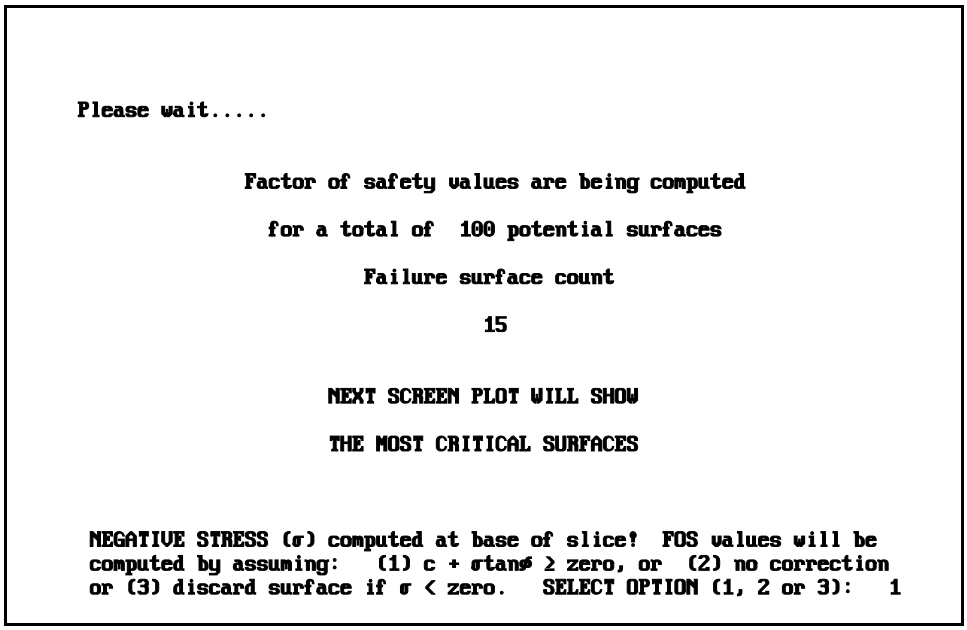
Please wait.....
Factor of safety values are being computed
for a total of 100 potential surfaces
Failure surface count
15
NEXT SCREEN PLOT WILL SHOW
THE MOST CRITICAL SURFACES
NEGATIVE STRESS (σ) computed at base of slice! FOS values will be
computed by assuming: (1) c + σtanΦ ≥ zero, or (2) no correction
or (3) discard surface if σ < zero. SELECT OPTION (1, 2 or 3): 1

Fig. 5.8. Prompt shown in lower part of screen regarding control of negative effective normal stress at base of slice

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At this prompt, the user is asked to select one of the following three options:

Option-1: Proceed with analysis, but enforce the condition that the Mohr-Coulomb shear strength, $\tau = c' + \sigma' \tan\varphi$, is ***always*** greater than or equal to zero.

Option-2: Proceed with analysis without any restrictive conditions concerning the computed shear strength;

Option-3: Proceed with the analysis, but only retain and summarize the factor of safety values for surfaces that did not have any calculated negative effective stress values (i.e., within the initial 95 percent of slices). *However, the parameters of the erroneous surface (and its FOS based on unrestricted ΔS values) are written to the* ***XSTABL*** *output file for information.*

The selected option remains in effect for the current analysis only. For subsequent analyses, the user will be prompted to make a "fresh" selection. An error message, ERROR #48, is written to the output file followed by an explanatory message indicating the option that was selected for the subsequent analysis.

Option 2 will always generate the lowest factors of safety as the strength mobilized along the failure surface will be a minimum because S_m may be calculated to be less than zero for some slices. Please note that the FOS values resulting from the selection of options (1) or (2) will be identical if values of $S_m < 0$ are not computed during the analysis. For the other cases where $S_m < 0$ is computed, the FOS values will be different depending on whether the user selects option (1) or (2). In certain circumstances where unusual geometric conditions exist, significantly different FOS values may be reported by **XSTABL**. Interestingly, it is also possible that if the φ-angle for the offending layer is increased, the FOS may be ***reduced*** due to the mobilization of *negative* frictional strength.

5.5 Plot of the Most Critical Surfaces

After all requested surfaces have been generated, the screen clears and a plot of the most critical surfaces will be displayed. The most critical surface (i.e. surface with the lowest factor of safety) is displayed with a thicker line and its factor of safety is given in the upper part of the screen. Fig. 5.9 shows the screen plot of the most critical surface for the EX_2.IPT input data. Only one surface is displayed as assigned via the SETUP1.STB file. Please note that the method of analysis (i.e. Bishop or Janbu) is also specified on the plot.

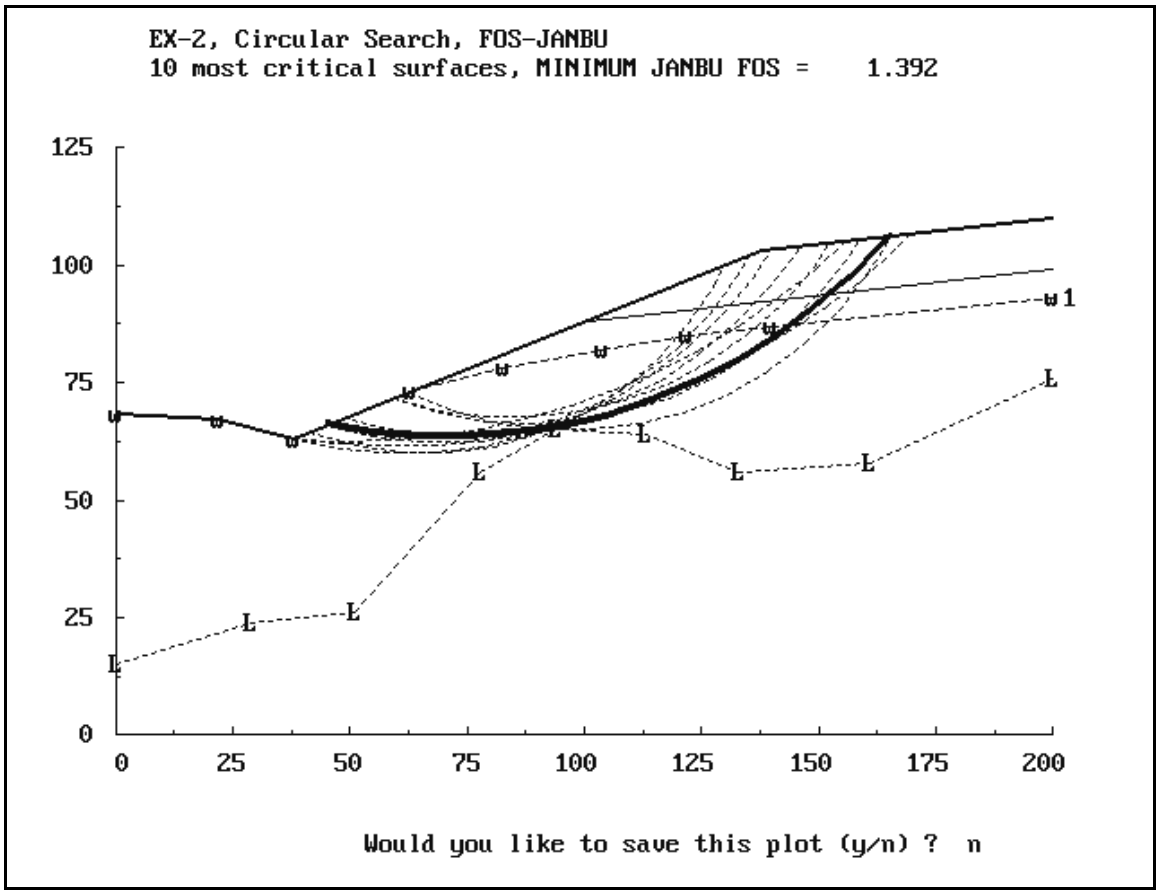

Fig. 5.9. View of screen plot showing the ten most critical surfaces and the minimum factor of safety (file EX_2.IPT)

Again the user has an option to save the screen plot for later printing. If the plot is saved, it is given the filename extension: *.GP3, *.WP3 or *.HP3 according to the graphical format requested by the user. An example of the printed plot of the ten most critical surfaces is included at the end of this chapter.

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5.6 Review of *.OPT Output File

At the completion of the analysis, and after the display of the *.GP3 plot, the user is offered an opportunity to browse through the output file and review the results of a successful analysis or check for possible errors. The user will also be informed at this time if erroneous data may have caused the program to terminate without completing the analysis. If the user elects to review the output file, the screen clears and the first 22 lines of the output file will be displayed, as shown in Fig. 5.10.

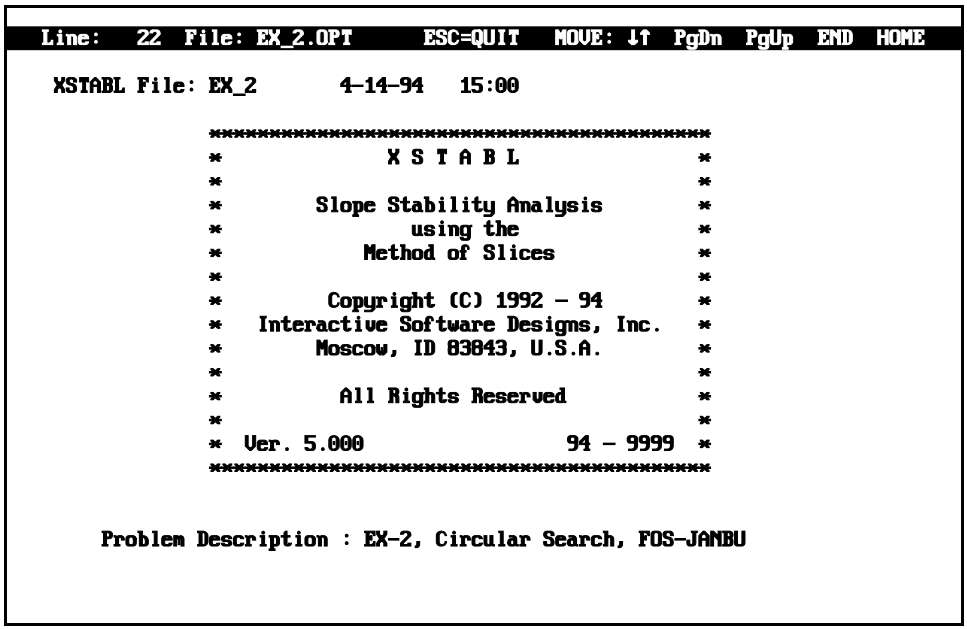

Line: 22 File: EX_2.OPT ESC=QUIT MOVE: ↓↑ PgDn PgUp END HOME
XSTABL File: EX_2 4-14-94 15:00
X S T A B L
Slope Stability Analysis
using the
Method of Slices
Copyright (C) 1992 - 94
Interactive Software Designs, Inc.
Moscow, ID 83843, U.S.A.
All Rights Reserved
Ver. 5.000 94 - 9999
Problem Description : EX-2, Circular Search, FOS-JANBU

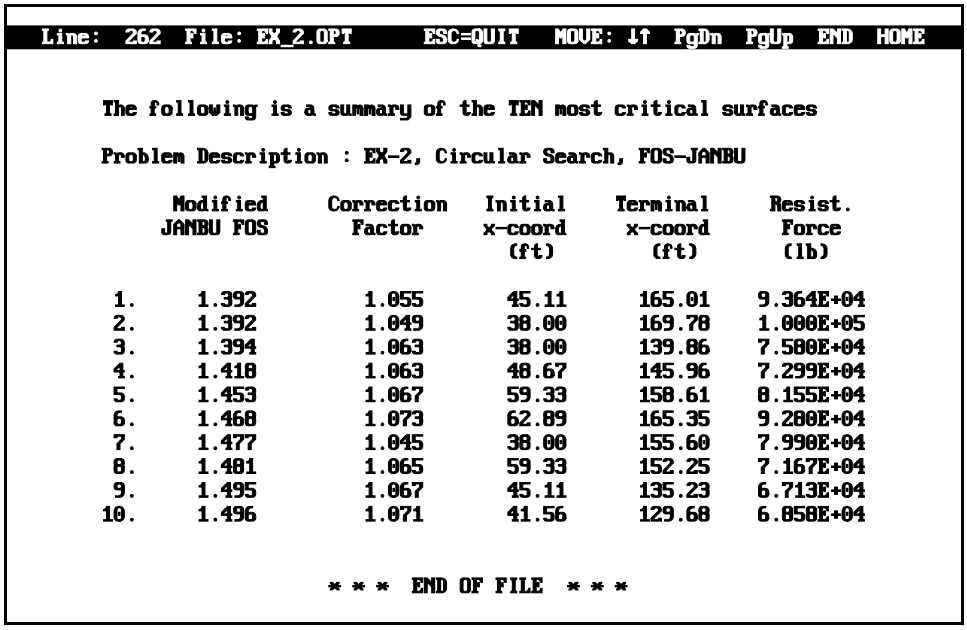
Fig. 5.10. View of the first screen of the output file: EX_2.OPT generated using the input file, EX_2.IPT

Note the unique identifier used to label the slope analysis files on the first line. This consists of: (1) filename, (2) date, (3) time, and (4) units . The first three of these identifiers are also written to the plot files as well (see Figs. 5.12 - 5.14) and helps the user maintain a reliable record of the slope analysis.

Under this option, the user may peruse through the file by using the **UP / DOWN** cursor keys to move through the output one-line at a time or the **PgUP / PgDn** key to move through the file more rapidly. The functions associated with these special keys are shown on the **top** line of the screen shown in Fig. 5.10.

A summary of the stability analysis (up to 10 most critical surfaces) is given at the end of the output file. This summary may be quickly viewed by pressing the **END** key which takes the user

to the last page as shown in Fig. 5.11. Pressing the **HOME** key at any point in the output file will return the user to the *first* page of the output file. Once you have reviewed the results, press **ESC** to exit and return to the main menu.



```
Line:  262  File: EX_2.OPT      ESC=QUIT   MOVE: ↓↑  PgDn  PgUp  END  HOME

      The following is a summary of the TEN most critical surfaces

      Problem Description : EX-2, Circular Search, FOS-JANBU

           Modified      Correction    Initial     Terminal      Resist.
           JANBU FOS       Factor      x-coord     x-coord       Force
                                         (ft)        (ft)        (lb)

       1.     1.392         1.055        45.11       165.01    9.364E+04
       2.     1.392         1.049        38.00       169.78    1.000E+05
       3.     1.394         1.063        38.00       139.86    7.580E+04
       4.     1.418         1.063        48.67       145.96    7.299E+04
       5.     1.453         1.067        59.33       158.61    8.155E+04
       6.     1.468         1.073        62.89       165.35    9.280E+04
       7.     1.477         1.045        38.00       155.60    7.990E+04
       8.     1.481         1.065        59.33       152.25    7.167E+04
       9.     1.495         1.067        45.11       135.23    6.713E+04
      10.     1.496         1.071        41.56       129.68    6.858E+04


                        * * *  END OF FILE  * * *
```

Fig. 5.11. Summary of the ten most critical surfaces from output file: EX_2.OPT viewed at the end of the analysis

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5.8 Review of Hardcopy Plots

The hardcopy plots of the files: *.GP1, *. GP2 or *.GP3 may be printed directly from **XSTABL** (using the "DOS FILE OPERATIONS" option from the Main Menu) or in batch-mode using the supplementary program **XPLOT**, discussed in the next section. Figs. 5.12 - 5.14 present a typical set of plots that may be generated using the example input data file, EX_2.IPT, for a slope stability analysis.

Note the unique identifier used to label the plots in the top left corner. This identifier consisting of: (1) filename, (2) date, and (3) time and is used to cross-link the *.OPT output file with the relevant plot files. As an added convenience, the following symbols are used to identify the different lines on the hardcopy plots of the slope geometry:

Limiting Boundaries, Lower/Upper : These limiting boundaries will be identified by the open triangular symbol: Δ.

Water Surfaces : These surfaces are identified on the plots by the following symbols:

"**w**" —— Phreatic Surface

"**p**" —— Piezometric Surface

The number of each such surface coincides with the water surface defined using the "Water Surfaces" option.

Most Critical Surface : is shown on the *.GP3, *.WP3 or *.HP3 plots by the line identified with the asterisks ("*").

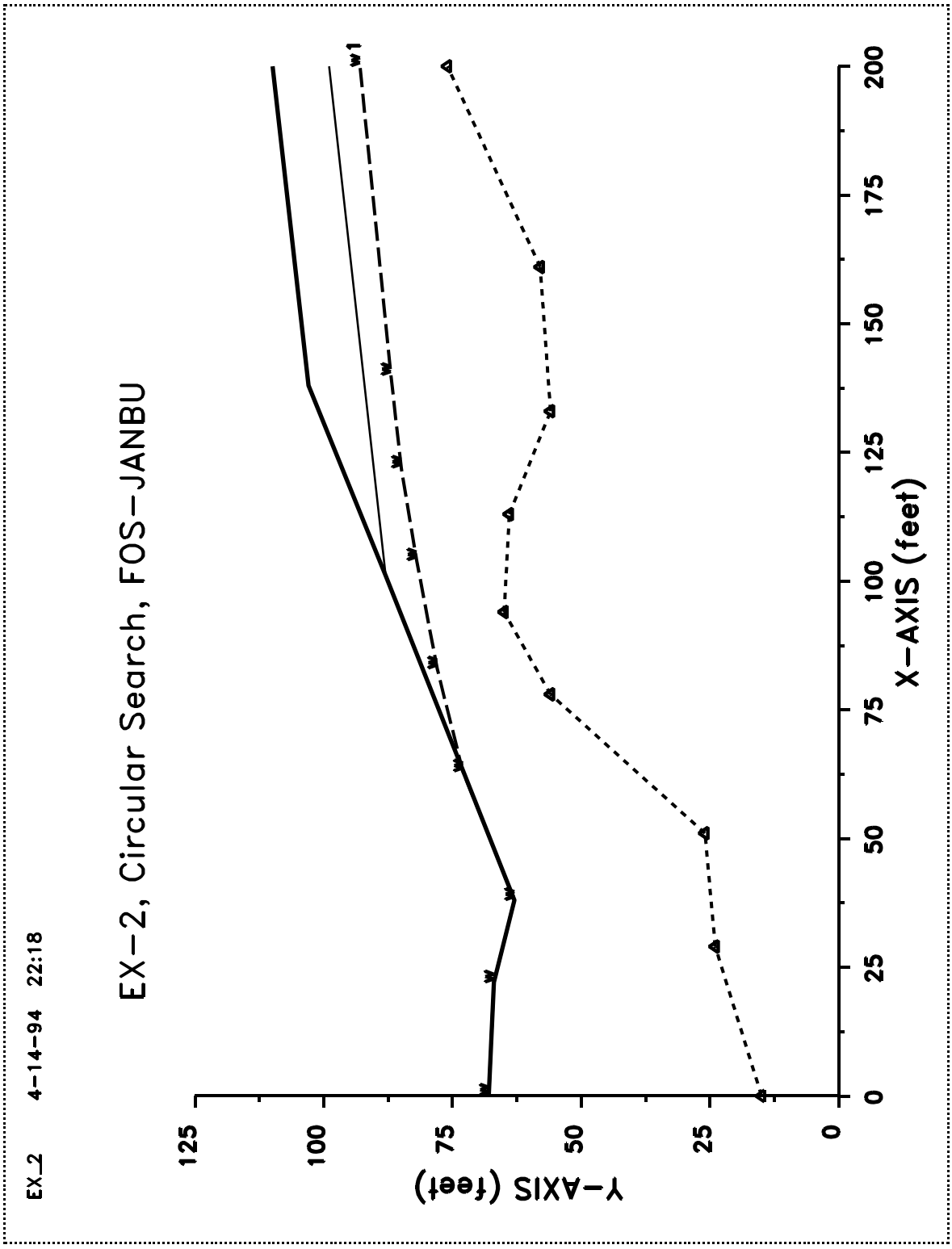

Fig. 5.12. Plot of the slope profile (file EX_2.GP1)

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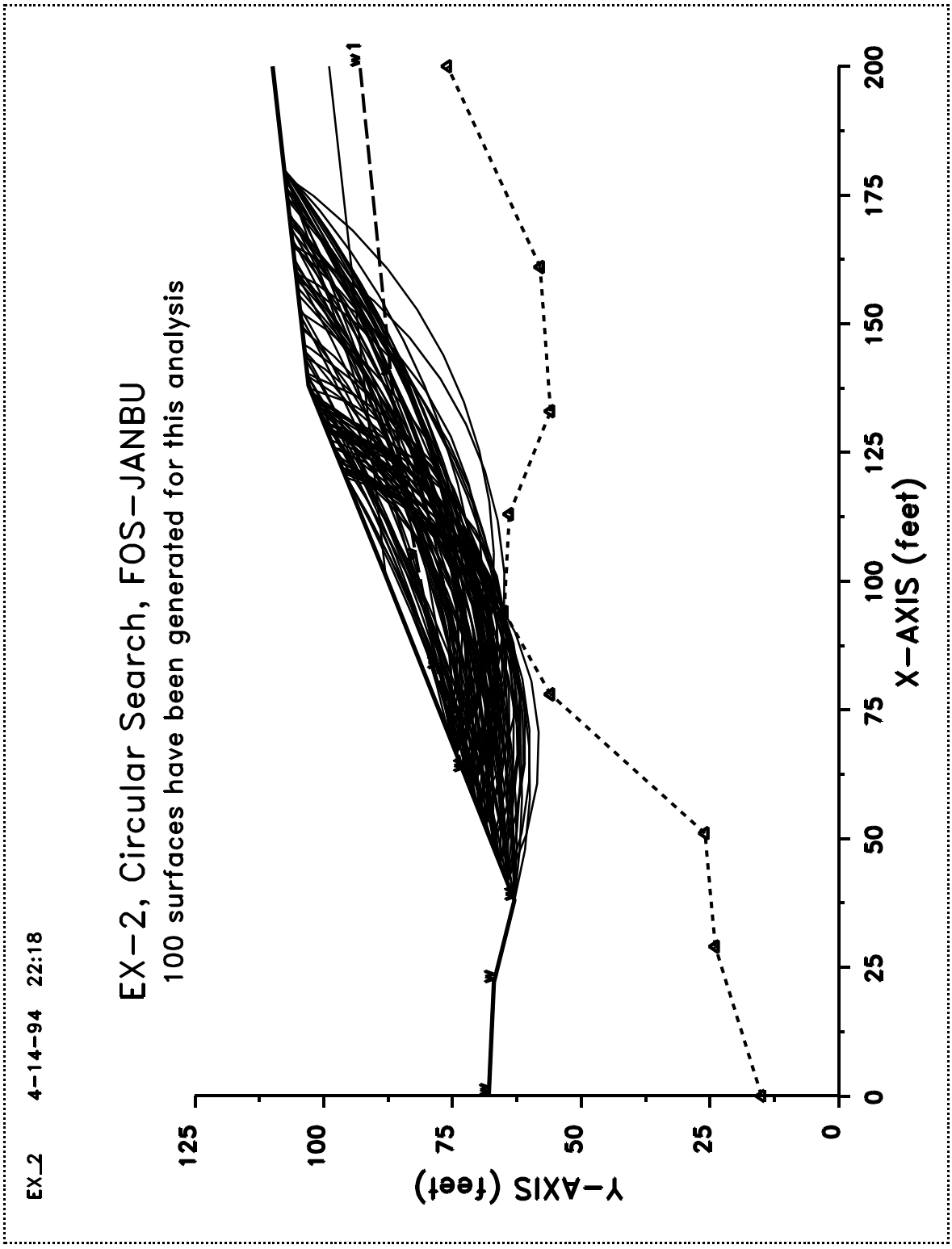

Fig. 5.13. Plot of slope with the first 25 generated failure surface (file EX_2.IPT)

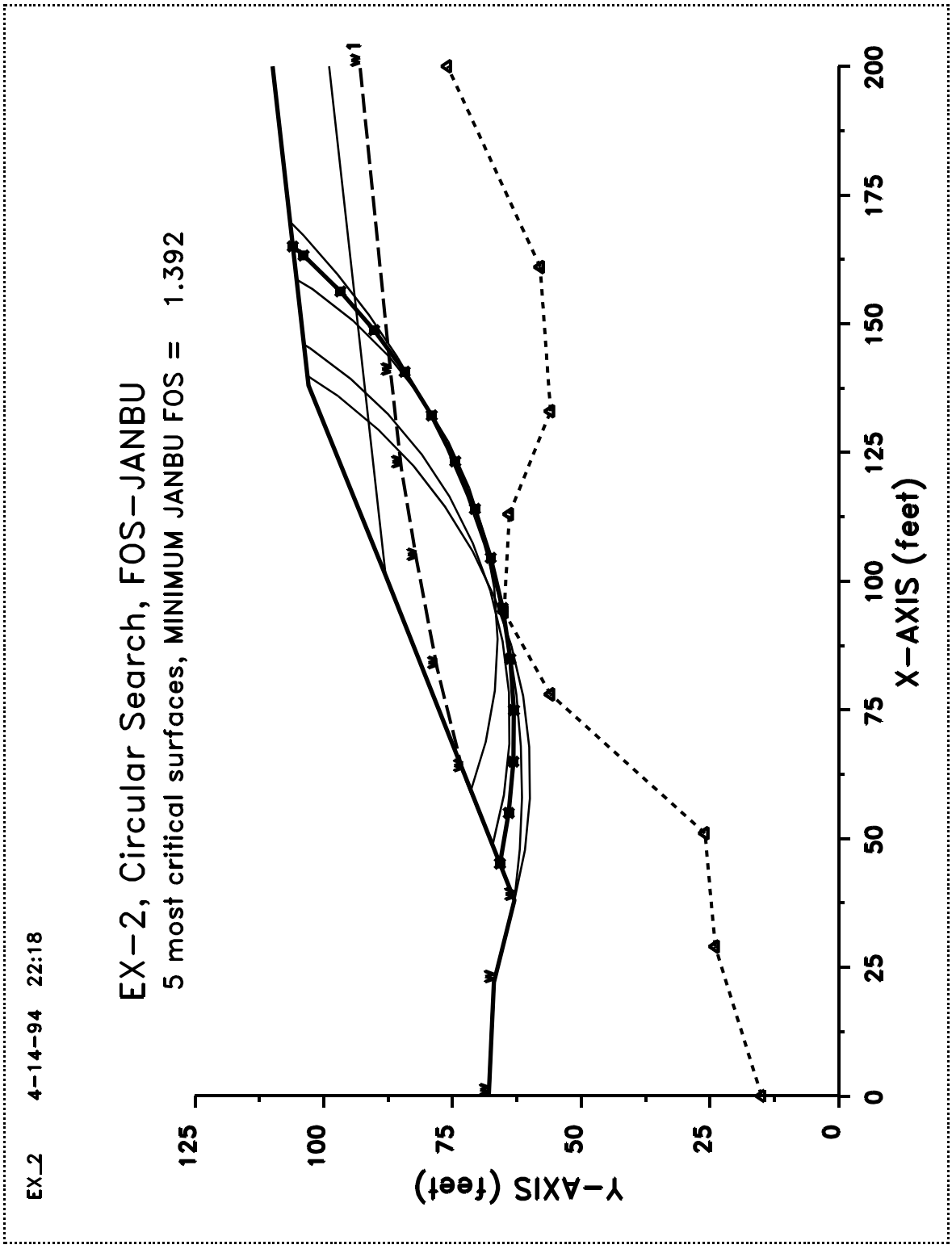

Fig. 5.14. Plot showing the 3 most critical failure surfaces (file EX_2.OPT)

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5.8 Analysis of a Single Surface

If the input datafile has been prepared for the analysis of a single surface, the user is asked to select a method of analysis from the menu displayed in Fig. 5.15. This figure shows the five options available for the analysis of a single, circular surface. For noncircular surfaces, the simplified Bishop procedure would not be offered as an analysis method.

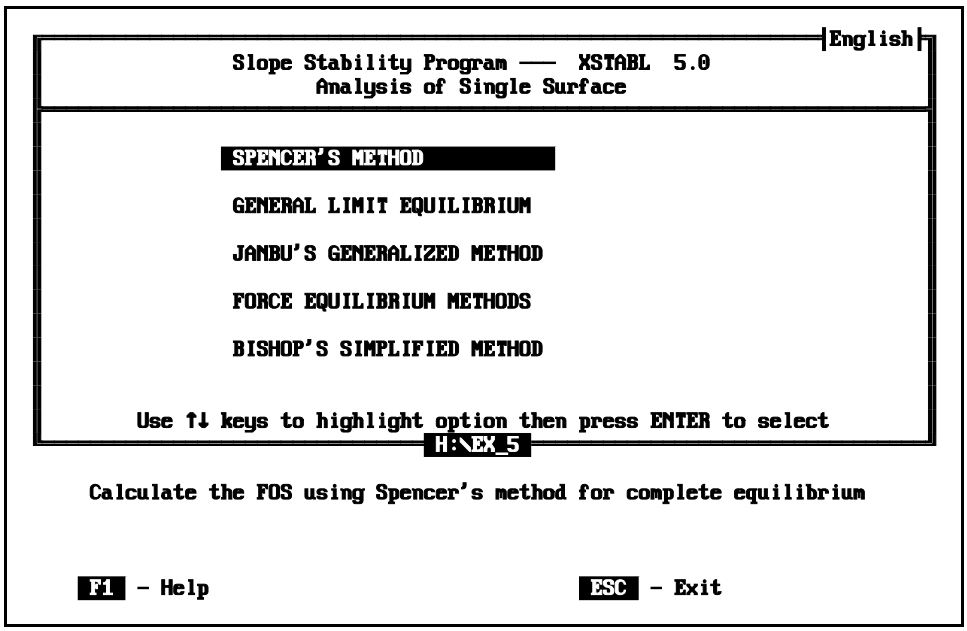
English
Slope Stability Program —— XSTABL 5.0
Analysis of Single Surface
SPENCER'S METHOD
GENERAL LIMIT EQUILIBRIUM
JANBU'S GENERALIZED METHOD
FORCE EQUILIBRIUM METHODS
BISHOP'S SIMPLIFIED METHOD
Use ↑↓ keys to highlight option then press ENTER to select
H:\EX_5
Calculate the FOS using Spencer's method for complete equilibrium
F1 - Help
ESC - Exit

Fig. 5.15. Options available for analysis of a single surface

The options shown in Fig. 5.15 are discussed below:

Spencer's Method satisfies complete force and moment equilibrium and assumes a constant interslice force angle.

General Limit Equilibrium Methods satisfy complete force and moment equilibrium using an assumed interslice force angle distribution. If this option is selected, the sub-menu shown in Fig. 5.16 will be presented, and the user will be asked to select an interslice force angle distribution. These distributions are specified as a function of the normalized x-coordinate along the failure surface. These normalized coordinates will thus range between 0.0 at the toe and 1.0 at crest of the failure surface. A sampling of the possible interslice force angle distributions is illustrated in Fig. 5.17.

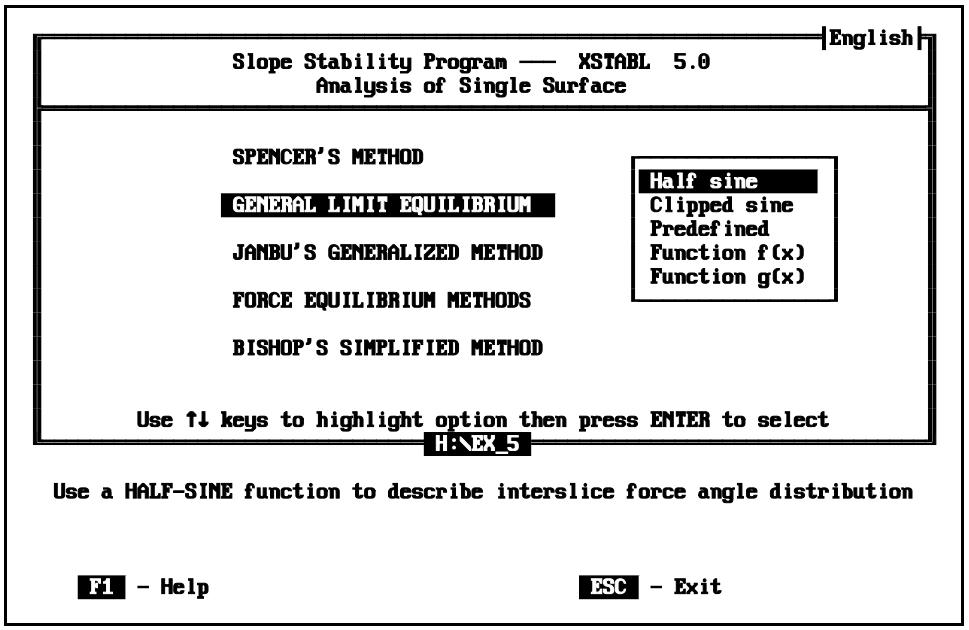

Fig. 5.16. Selection of interslice force angle distributions for the General Limit Equilibrium (GLE) method of analysis

XSTABL supports the following interslice force angle distributions:

(a) *Half-Sine* -- a smooth function that increases from 0.0 at the toe to 1.0 at the mid-point, before decreasing to 0.0 at the crest of the failure surface. The user does not have to supply any further data.

(b) *Clipped, Half-Sine* -- similar to above function except that non-zero values may be assigned at the toe and crest of the failure surface. The user is prompted to provide the clipped-values at the toe and crest of the failure surface.

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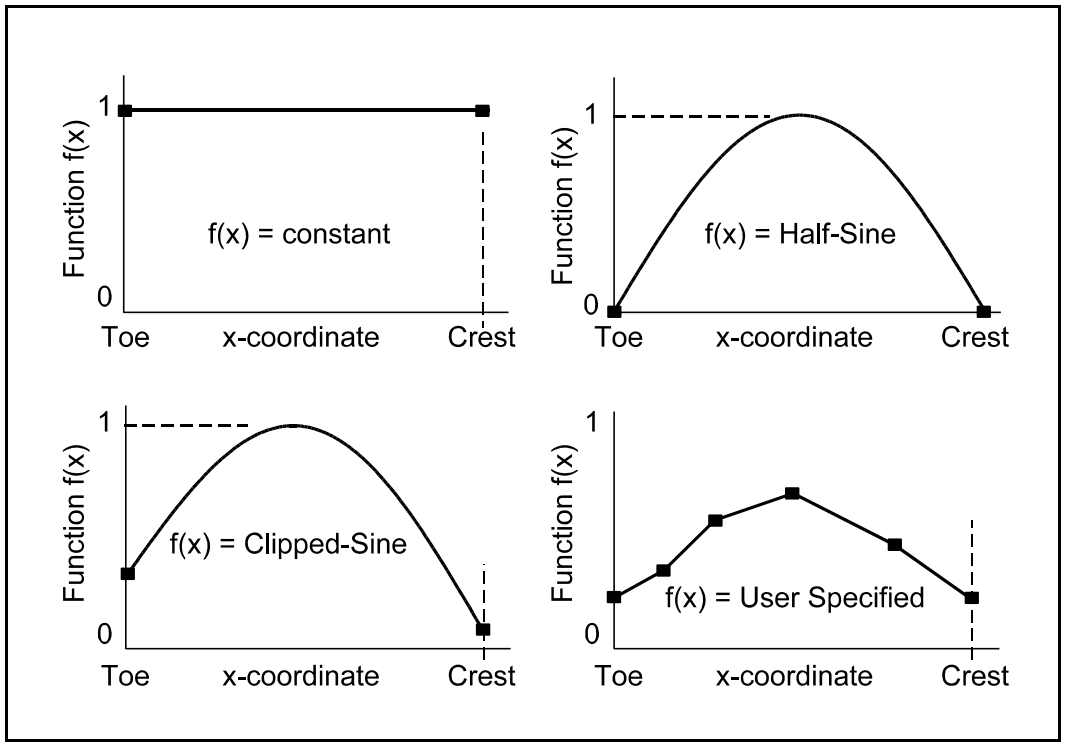

Fig. 5.17. Example interslice force angle distributions available for the GLE method of analysis

(c) *User-specified* -- a discrete set of amplitudes given as a function of the normalized x-coordinate of the failure surface may be specified to simulate a special distribution. This data may be imported from a file that has the ***.GLE** extension. For this procedure, up to 11 pairs of normalized x-coordinates and amplitudes may be input into the data table shown in Fig. 5.18.

Upon exiting this data table by pressing the **ESC** key, you will be asked if you wish to save the data for this function. If you want to reuse this function again, enter an appropriate filename or accept the suggested default filename. This saved data will be written to a file with a ***.GLE** extension and thus may be used for other analyses.

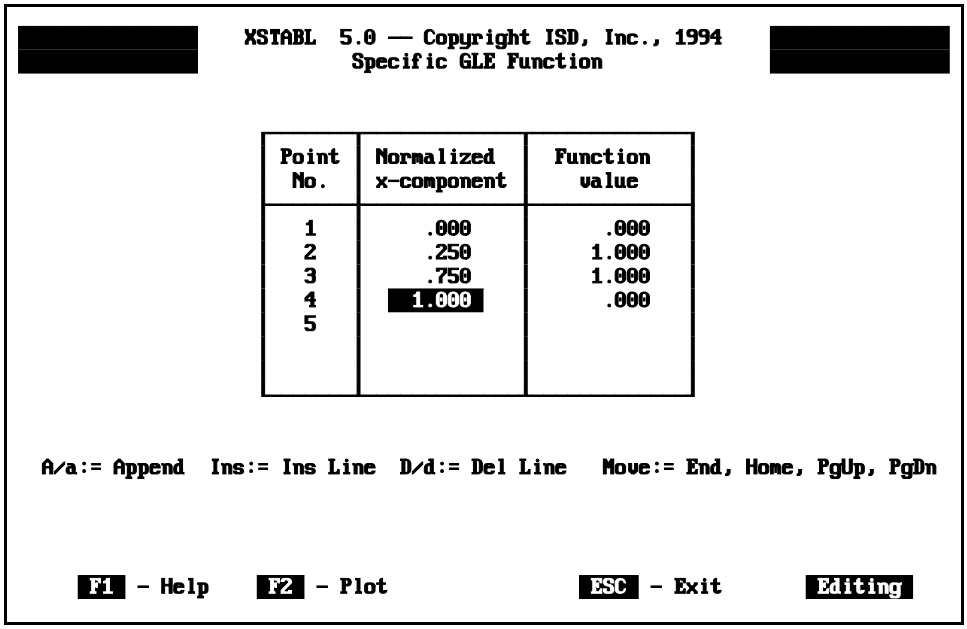

Fig. 5.18. Example data table for a *user-specified* interslice force angle distribution for the GLE method of analysis

(d) *Function f(x)* -- uses the assumption that the interslice force angle is parallel to the inclination of the surface of the slope, as shown in Fig. 5.19 as function, f(x). The user does not have to supply any further data as the program calculates these angles.

(e) *Function g(x)* -- uses the assumption that the interslice force angle is the average of the inclination of the top and base of each slice, as shown in Fig. 5.19. This is the same function proposed by Lowe and Karafiath for the force equilibrium only procedure. The user does not have to supply any further data.

Please note that the solution procedure assumes that the discrete amplitudes of these functions is always less than or equal to 1.0.

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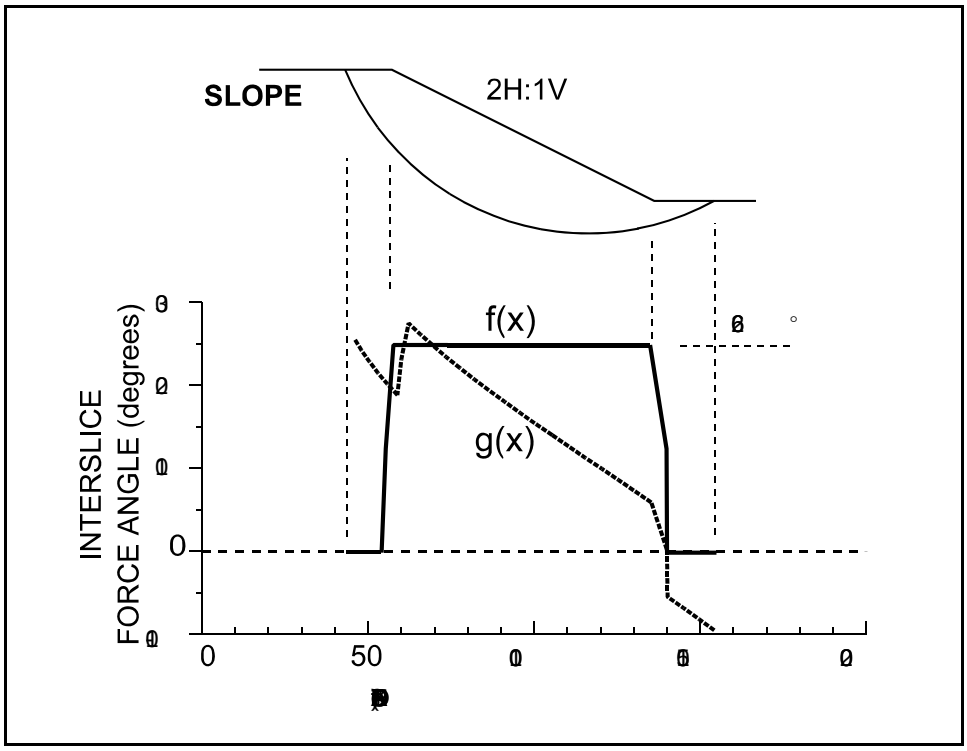

Fig. 5.19. The interslice force angle distributions, f(x) and g(x) available for the GLE method

Janbu's GPS Method satisfies complete force equilibrium for all slices and moment equilibrium for all slices except the last slice at the crest of the failure surface. For this method to work successfully, the user must specify a *reasonable* location of the thrust line as it passes through the slide mass. The ratio y/h_R, where y is the thrust-line height and h_R is the interslice height, is used to specify a thrust line location as a function of the normalized x coordinate along the failure surface. **XSTABL** allows the user to import this data from an existing file that has the ***.RJB** extension, or enter the information into the data table shown in Fig. 5.20.

Upon exiting this data table by pressing the **ESC** key, you will be asked if you wish to save the data for this function. If you want to reuse this function again, enter an appropriate filename or accept the suggested default filename. This saved data will be written to a file with a ***.RJB** extension and thus may be used for other analyses.

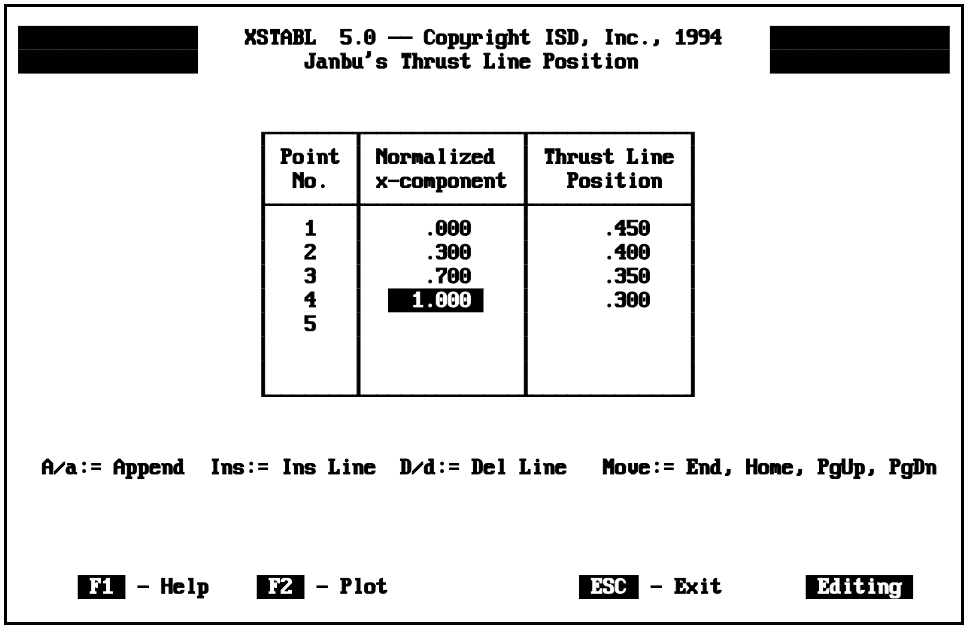

Fig. 5.20. Example data table for specifying the thrust-line location for Janbu's GPS procedure

Force Equilibrium Methods in this category satisfy force equilibrium conditions only and moment equilibrium is not considered for the slide mass. These methods iterate with the value of the factor of safety and the presumed interslice force angles until force equilibrium is satisfied in two directions. As moment equilibrium is not considered, the location of a thrust line is not calculated as part of the solution. The available methods are:

(a) *Simplified Janbu* -- The interslice forces are assumed to be horizontal (i.e. $\theta = 0^\circ$), resulting in zero interslice shear forces. The user does not have to supply any additional data.

(b) *Corps of Engrg. – 1* -- For this method, the inclination of the interslice forces is assumed to be a constant angle equal to the slope of the *chord* connecting the two ends of the failure surface, as shown in Fig. 5.21. The user does not have to supply any additional data.

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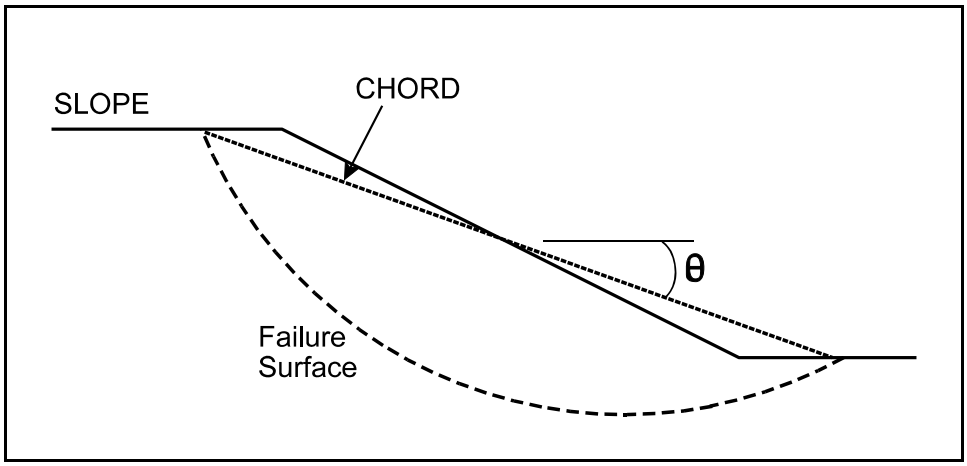

Fig. 5.21. Definition of the constant interslice force angle used by the Corps of Engrg. - 1 method (Force Equilibrium)

(c) *Corps of Engrg. – 2* -- The inclination of the interslice forces is assumed to be parallel to the surface slope directly above the vertical interslice boundary, as shown in Fig. 5.19 as the f(x) function. This distribution is the same as the f(x) distribution available for the GLE method. Additional data is not required for this option.

(d) *User Specified* -- A constant angle for the inclination of the interslice forces is specified in the data table, as shown in Fig. 5.22. Once the angle is inserted, press the ENTER key to register the value followed by the ESC key to proceed with the analysis.

(e) *Lowe and Karafiath* -- This method sets the inclination of the interslice forces equal to the average of the surface and base angles of the slice (see Fig. 5.19, function g(x)). The average values are calculated by the program and the user does not have to supply any further data.

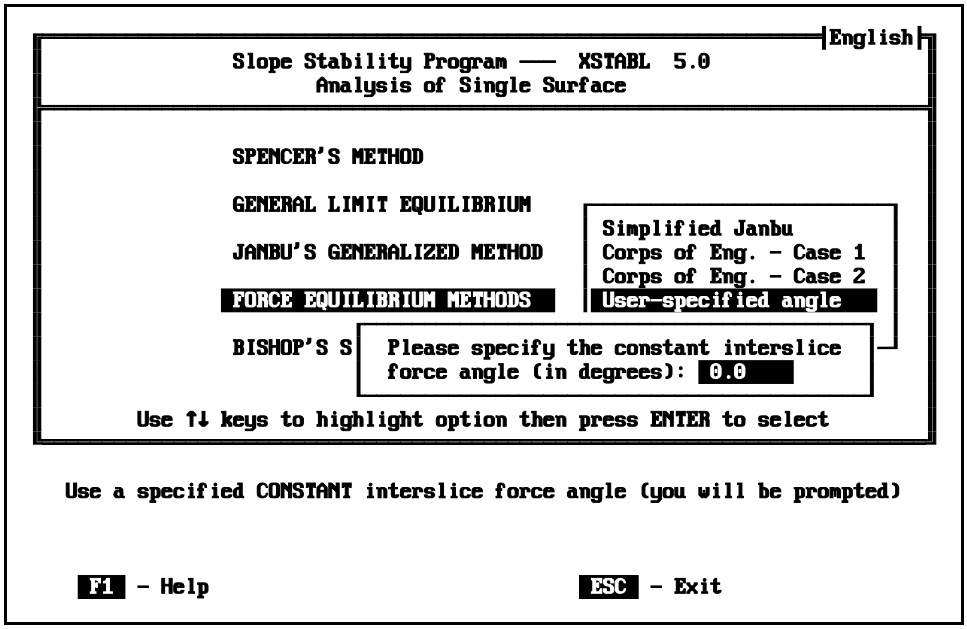
English
Slope Stability Program —— XSTABL 5.0
Analysis of Single Surface
SPENCER'S METHOD
GENERAL LIMIT EQUILIBRIUM
JANBU'S GENERALIZED METHOD
FORCE EQUILIBRIUM METHODS
BISHOP'S S
Simplified Janbu
Corps of Eng. - Case 1
Corps of Eng. - Case 2
User-specified angle
Please specify the constant interslice force angle (in degrees): 0.0
Use ↑↓ keys to highlight option then press ENTER to select
Use a specified CONSTANT interslice force angle (you will be prompted)
F1 - Help
ESC - Exit

Fig. 5.22. Example data table for specifying the *constant* interslice force angle used for the Force Equilibrium method

Simplified Bishop Method assumes horizontal (i.e. $\theta = 0°$) interslice forces, resulting in zero interslice shear forces. This procedure satisfies overall moment equilibrium for all slices, however, force equilibrium in considered in one direction only. The user does not have to supply any data.

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5.9 Output from the Analysis of a Single Surface

If a single surface is analyzed, **XSTABL** provides detailed information concerning the slices and the data used to calculate the factor of safety. This data is summarized in four tables for all analyses except for the simplified Bishop and Janbu methods. In the case of the simplified methods, only the data in Tables 1 and 2 is written to the output file.

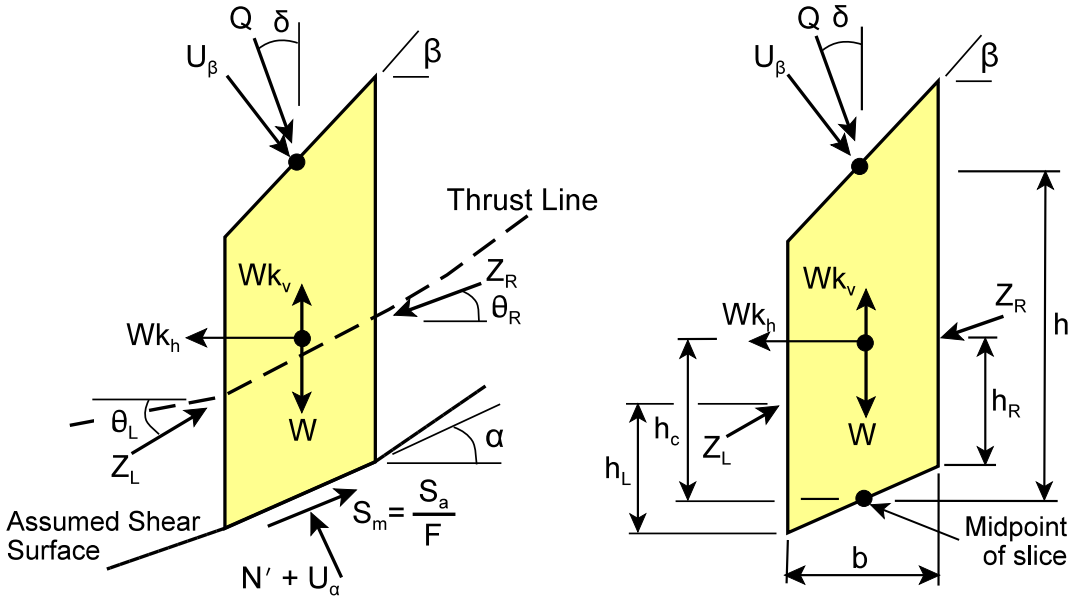

Fig. 5.23. Definition of reported slice parameters following the analysis of a single specified surface

With reference to the typical slice shown in Fig. 5.23, this data provides the following:

TABLE 1

Slice:	Slice number (n)
x-base:	x-coordinate of the center of the slice base
y-base:	y-coordinate of the center of the slice base
height:	average height of slice (h)
width:	width of slice (b)
alpha:	inclination of the base of the slice (α)
beta:	inclination of the top of slice (β)
weight:	calculated weight of slice (W)

TABLE 2

Sigma:	normal effective stress (σ_n')
c-value:	strength intercept (c) at base of slice
phi:	angle of internal friction (φ) at base of slice
U-base:	pore water force at base of slice (U_α)
U-top:	pore water force acting on top of slice (U_β)
Q-top:	surcharge force on top of slice (Q)
Delta:	inclination of the surcharge force on top of slice (δ)

TABLE 3

Base x-coord:	x-coordinate of the center of the slice base
Normal Stress:	total normal stress on base of slice(σ_n)
Vertical Stress:	total vertical stress at center of slice base (σ_v)
Pore Water Pressure:	pore water pressure at center of slice base
Shear Stress:	average shear stress along base of slice

TABLE 4

Right x-coord:	x-coordinate at vertical boundary between slices
Force Angle:	angle of the interslice force (θ)
Interslice Force:	magnitude of the interslice force (Z)
Force Height:	location of interslice force, h_R, above failure surface
Boundary Height:	height of vertical interslice boundary
Height Ratio:	ratio of the height of the interslice force location and the vertical height of the interslice boundary

This data is useful for examining single surfaces in greater detail and for evaluating the computational algorithms used by **XSTABL**. It can also be used to evaluate effects of tie-back loads, geotextile reinforcement and for possibly calculating the factor of safety using an alternative methods.

As an aid to better understanding of the computed solution, and to judge its reasonableness, a plot (*.GP4) is also generated to visually display much of the data presented in Tables 3 and 4, discussed above. An example of this type of plot is shown in Fig. 5.24.

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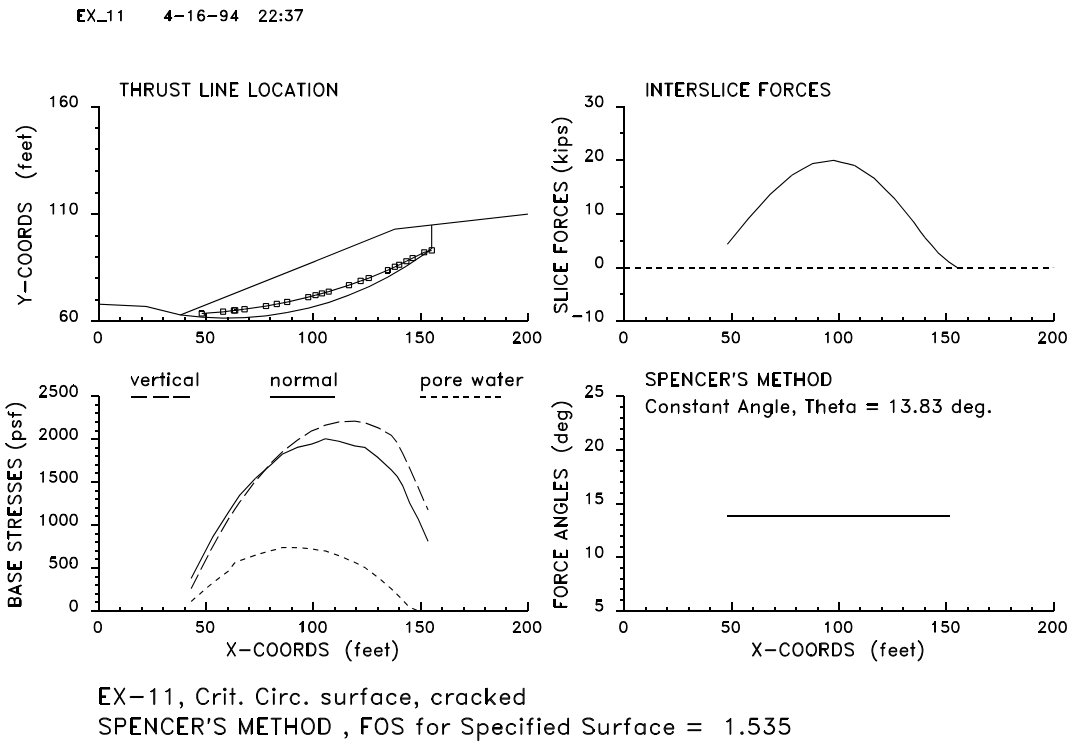

Fig. 5.24. Plot file EX_11.GP4 generated for Spencer's Solution

The four graphs presented in this figure are:

(a) **Thrust Line Location** (upper-left) -- shows the location of the thrust line computed using the Spencer's method or the GLE method. The location of the *assumed* line is shown for the Janbu GPS procedure. For a reasonable solution, the thrust line should be located within the failure slide mass.

(b) **Stress plots** (lower-left) -- these show the variation of the total vertical and normal stresses along the failure surface. The lines shown connect the calculated *average* value of the vertical and normal stress at the center of the slice base. If a pore water pressure exists along the failure surface, it is also plotted on this graph. For a reliable solution, the calculated normal stresses should rarely exceed the reported vertical stresses.

(c) **Interslice Forces** (upper-right) -- this plot shows the variation of the calculated interslice forces within the slide mass. For a reasonable solution, the distribution should be relatively smooth and indicate only compressive forces (i.e. positive) throughout the failure surface. In some cases, tensile forces reported very close to the crest of a failure surface may be tolerated or alternatively, a cracked zone should be implemented into the slope geometry. The insertion of such a cracked zone will often relieve the tensile forces and improve the location of the thrust line. *For such cases, the user should also seriously consider the inclusion of a hydrostatic force that may be attributed to a water-filled crack.*

(d) **Interslice Force Inclination** (lower-right) -- this plot shows the computed values of the interslice force angles and the overall distribution of their range, as assumed by the GLE methods. For the Janbu GPS procedure, this plot gives the values of the interslice force angles that have been calculated on the basis of the assumed location of the thrust line. For a reasonable solution, the magnitude of the interslice force angle should typically be less than the angle of internal friction of the soils within the failure mass. For cases where different soils are present within a typical slice, an average φ-value will have to be selected to check for compliance with this condition.

The force equilibrium methods do not satisfy moment equilibrium and thus the location of the thrust line is not reported on a *.GP4 plot for these cases.

As a typical example, the tables generated using file **EX_11.IPT**, which includes the analysis of the critical failure surface identified by the search discussed in Appendix A, are given on the next four pages. For this case, an 11-foot-deep cracked section was assumed and Spencer's Method was selected for the analysis. The **EX_11.GP4** plot that was generated for this solution is presented in Fig. 5.24.

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```
**************************************
SUMMARY OF INDIVIDUAL SLICE INFORMATION
**************************************
```

TABLE 1:

Slice	x-base (ft)	y-base (ft)	height (ft)	width (ft)	alpha	beta	weight (lb)
1	42.97	62.48	2.50	9.94	-6.03	21.64	3085.
2	52.94	61.74	7.19	9.99	-2.39	21.64	8918.
3	60.47	61.59	10.33	5.07	1.24	21.64	6497.
4	63.27	61.65	11.38	.54	1.24	21.64	764.
5	65.74	61.70	12.30	4.39	1.24	21.64	6701.
6	72.91	62.17	14.68	9.96	4.88	21.64	18061.
7	80.45	62.98	16.86	5.10	8.51	21.64	10591.
8	85.39	63.72	18.09	4.79	8.51	21.64	10626.
9	92.67	65.13	19.57	9.78	12.14	21.64	23387.
10	99.28	66.67	20.65	3.44	15.78	21.64	8650.
11	102.50	67.58	21.03	3.00	15.78	22.07	7675.
12	105.59	68.45	21.41	3.19	15.78	22.07	8283.
13	111.90	70.56	21.86	9.43	19.41	22.07	24933.
14	119.31	73.37	22.05	5.38	23.05	22.07	14287.
15	123.91	75.33	21.96	3.82	23.05	22.07	10057.
16	130.29	78.38	21.49	8.94	26.68	22.07	22874.
17	136.38	81.58	20.76	3.25	30.31	22.07	7971.
18	139.00	83.11	20.00	2.00	30.31	6.44	4715.
19	141.69	84.69	18.73	3.39	30.31	6.44	7450.
20	144.84	86.65	17.12	2.90	33.95	6.44	5795.
21	148.98	89.45	14.79	5.40	33.95	6.44	9294.
22	153.42	92.60	12.14	3.48	37.58	6.44	4913.

```
--------------------------------
ITERATIONS FOR SPENCER'S METHOD
--------------------------------
```

Iter #	Theta	FOS_force	FOS_moment
2	13.7337	1.5344	1.5587
3	13.8274	1.5348	1.5344

```
SLICE INFORMATION ... continued :
```

TABLE 2:

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	Q-top (lb)	Delta
1	320.9	500.0	14.00	1352.	11.	0.	.00
2	641.1	500.0	14.00	3892.	32.	0.	.00
3	824.0	500.0	14.00	2834.	24.	0.	.00
4	841.2	500.0	14.00	363.	1.	0.	.00
5	920.0	500.0	14.00	3091.	0.	0.	.00
6	1072.8	500.0	14.00	7814.	0.	0.	.00
7	1205.4	500.0	14.00	4359.	0.	0.	.00
8	1304.1	500.0	14.00	4294.	0.	0.	.00
9	1402.2	500.0	14.00	8859.	0.	0.	.00
10	1464.3	500.0	14.00	3105.	0.	0.	.00
11	1521.1	500.0	14.00	2654.	0.	0.	.00
12	1572.4	500.0	14.00	2776.	0.	0.	.00
13	1601.0	500.0	14.00	7743.	0.	0.	.00
14	1627.9	500.0	14.00	3971.	0.	0.	.00
15	1677.3	500.0	14.00	2529.	0.	0.	.00
16	1677.2	500.0	14.00	4645.	0.	0.	.00
17	1661.4	500.0	14.00	1163.	0.	0.	.00
18	1652.3	500.0	14.00	539.	0.	0.	.00
19	1596.3	500.0	14.00	602.	0.	0.	.00
20	1457.5	500.0	14.00	179.	0.	0.	.00
21	1281.7	500.0	14.00	0.	0.	0.	.00
22	975.2	500.0	14.00	0.	0.	0.	.00

SPENCER'S (1973) - TOTAL Stresses at center of slice base

TABLE 3:

Slice #	Base x-coord (ft)	Normal Stress (psf)	Vertical Stress (psf)	Pore Water Pressure (psf)	Shear Stress (psf)
1	42.97	456.1	311.2	135.2	377.9
2	52.94	1030.2	895.6	389.2	429.9
3	60.47	1383.4	1287.2	559.4	459.6
4	63.27	1511.8	1415.8	670.7	462.4
5	65.74	1623.8	1525.8	703.7	475.2
6	72.91	1854.1	1812.6	781.4	500.0
7	80.45	2049.9	2075.1	844.6	521.6
8	85.39	2191.3	2220.2	887.3	537.6
9	92.67	2288.1	2392.2	885.9	553.6
10	99.28	2333.4	2516.2	869.1	563.7

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11	102.50	2372.4	2558.2	851.3	572.9
12	105.59	2411.1	2599.9	838.7	581.2
13	111.90	2375.3	2643.5	774.3	585.9
14	119.31	2306.8	2654.1	678.9	590.2
15	123.91	2286.6	2633.3	609.3	598.3
16	130.29	2141.7	2560.0	464.5	598.2
17	136.38	1970.7	2456.0	309.4	595.7
18	139.00	1885.1	2357.5	232.8	594.2
19	141.69	1749.6	2199.5	153.4	585.1
20	144.84	1508.9	1999.1	51.3	562.6
21	148.98	1281.7	1722.1	.0	534.0
22	153.42	975.2	1413.3	.0	484.2

SPENCER'S (1973) - Magnitude & Location of Interslice Forces

TABLE 4

Slice #	Right x-coord (ft)	Force Angle (degrees)	Interslice Force (lb)	Force Height (ft)	Boundary Height (ft)	Height Ratio
1	47.94	13.83	4367.	1.75	5.00	.350
2	57.93	13.83	9246.	2.95	9.38	.315
3	63.00	13.83	11496.	3.41	11.28	.302
4	63.54	13.83	11736.	3.46	11.48	.301
5	67.93	13.83	13726.	3.87	13.13	.295
6	77.90	13.83	17235.	4.52	16.23	.279
7	83.00	13.83	18364.	4.72	17.49	.270
8	87.79	13.83	19398.	4.92	18.68	.263
9	97.56	13.83	20014.	5.07	20.45	.248
10	101.00	13.83	19676.	5.03	20.85	.241
11	104.00	13.83	19375.	5.00	21.21	.235
12	107.19	13.83	19046.	4.96	21.61	.230
13	116.62	13.83	16607.	4.62	22.11	.209
14	122.00	13.83	14439.	4.27	22.00	.194
15	125.82	13.83	12966.	4.03	21.92	.184
16	134.75	13.83	8567.	3.23	21.05	.153
17	138.00	13.83	6707.	2.87	20.47	.140
18	140.00	13.83	5660.	2.66	19.53	.136
19	143.39	13.83	4133.	2.29	17.93	.127
20	146.29	13.83	2780.	1.86	16.31	.114
21	151.68	13.83	952.	.91	13.28	.069
22	155.16	.00	-1.	-.87	11.00	-.079

```
-------------------------------------------------------
  AVERAGE VALUES ALONG FAILURE SURFACE
-------------------------------------------------------

       Total Normal Stress =   2312.07  (psf)
       Pore Water Pressure =    536.74  (psf)
       Shear Stress        =    614.18  (psf)

       Total Length of failure surface =  124.39  (ft)

-------------------------------------------------------
```

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 1.535

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CHAPTER 6

6.0 HARDCOPY PLOTS USING XPLOT

Screen plots that have been saved to disk during the slope stability analysis may be printed directly from **XSTABL** or by using the supplementary program **XPLOT.EXE**. This program also offers a "user-friendly" interface and allows the user to select one or up to a maximum of 180 plot files (i.e. *.GP1, *.GP2, *.GP3 or *.GP4) for printing. Please note that this program is not available directly from **XSTABL**, and so the user must exit to DOS and execute the **XPLOT** program separately.

When the user types "**XPLOT**" from the DOS prompt, the main menu (Fig. 6.1) allows the user to select the device and resolution for printing the previously saved screen plots.

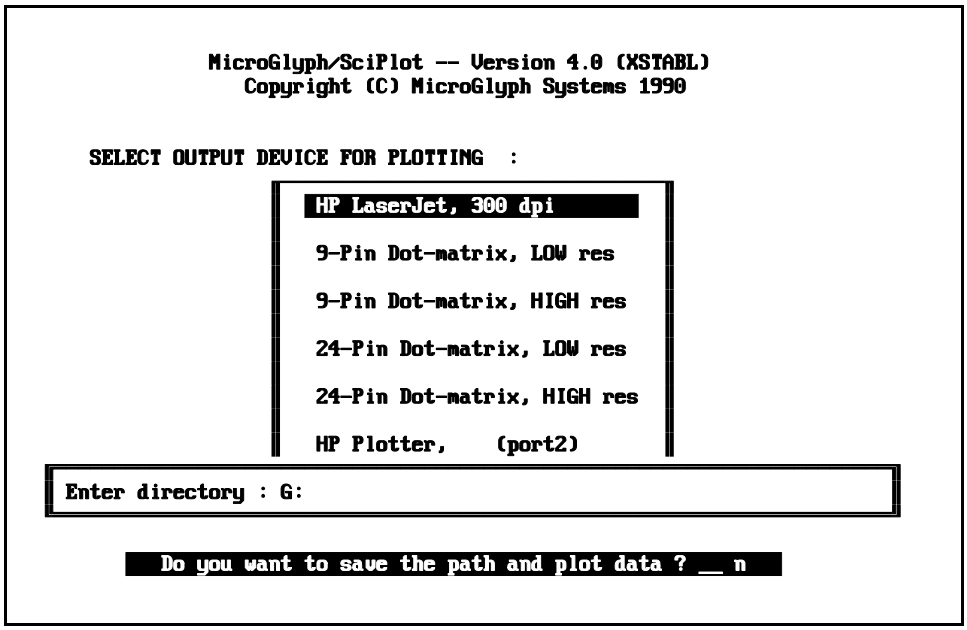
MicroGlyph/SciPlot -- Version 4.0 (XSTABL)
Copyright (C) MicroGlyph Systems 1990
SELECT OUTPUT DEVICE FOR PLOTTING :
HP LaserJet, 300 dpi
9-Pin Dot-matrix, LOW res
9-Pin Dot-matrix, HIGH res
24-Pin Dot-matrix, LOW res
24-Pin Dot-matrix, HIGH res
HP Plotter, (port2)
Enter directory : G:
Do you want to save the path and plot data ? __ n

Fig. 6.1. Device selection and prompt for directory name using **XPLOT** for hardcopy plots with the *.GP? format

Initially, the default option is set to "HP LaserJet, 300 dpi" but the user may implement any one of the other three options by highlighting the appropriate device and pressing **ENTER** to make the selection. Once the device has been selected, the user will be prompted for the directory where the plot files are located as shown in Fig. 6.1. If a directory name is not provided, the program will default to the current directory. Upon typing an acceptable directory name, **XPLOT** will offer to save information concerning the selected device and directory name to a special startup file, SETUP.XTB. This is intended as a convenient feature for assigning default output device and directory parameters. After responding to the prompt for saving the path and plot data, the screen will clear and the **XSTABL** plot files will be displayed, as shown in Fig. 6.2. Up to **three** pages, or a total of 180 filenames, can be accommodated by this program at any one time.

A typical listing, Fig. 6.2, shows the three example files: EX_1.GP1, EX_1.GP2 and EX_1.GP3, included on the program disks. The available commands for selecting or canceling files for plotting are given in the lower part of the screen, and are discussed below:

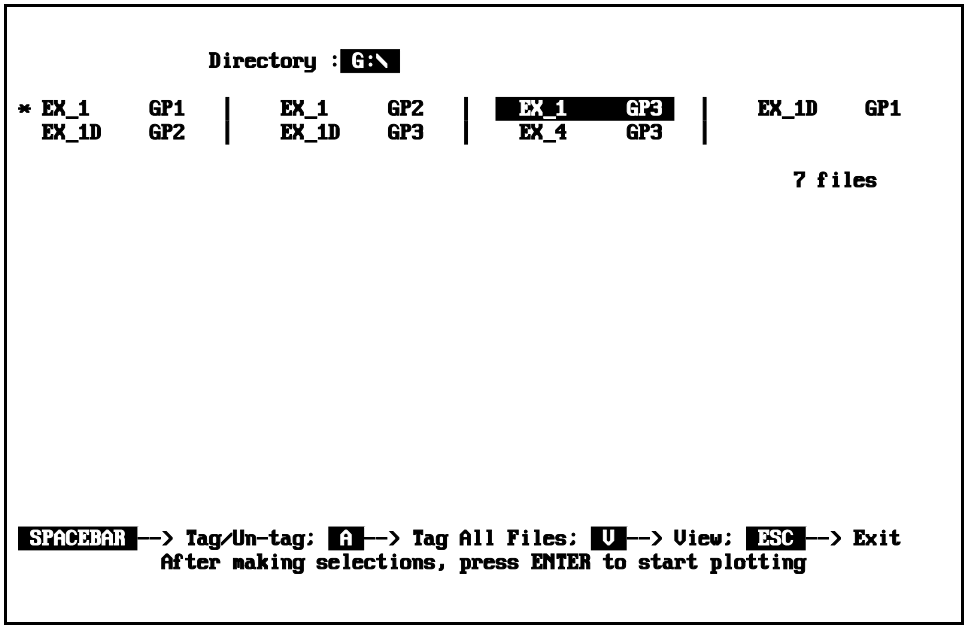
Directory : G:\
* EX_1 GP1 | EX_1 GP2 | EX_1 GP3 | EX_1D GP1
EX_1D GP2 | EX_1D GP3 | EX_4 GP3 |
7 files
SPACEBAR --> Tag/Un-tag: A --> Tag All Files: V --> View: ESC --> Exit
After making selections, press ENTER to start plotting

Fig. 6.2. Typical directory listing of printable graphics file using the supplied program, **XPLOT**

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SPACEBAR By pressing the SPACEBAR, the user may "tag" or "untag" individual files. A tagged files is identified by an asterisk ("*") on the left side of the filename, as shown in Fig. 6.2 (file : "EX_1.GP1").

If the SPACEBAR is pressed while the cursor is highlighting a previously tagged file, the "tag" is erased and the file removed from the print queue.

All If the "a" (or "A") key is pressed, ***all*** files in the displayed directory will be "tagged" for possible printing.

View The *.GP? files may be "viewed" by pressing "V" (or "v") while the pertinent filename is highlighted by the cursor.

ESC If the user makes a mistake with the directory name, or finds that there are no plot files, pressing the **ESC** key will terminate **XPLOT** and return the user back to the DOS prompt.

If the user wishes to cancel the printing in progress, pressing the **CTRL-BREAK** key or the **CTRL-C** key will terminate the plotting and return the user to the DOS command line. Please note that the plot data that has already been transmitted to the printer will be printed before the printer comes to a stop.

Since the selection of several files for plotting places the output device in a batch-mode, it is very useful for printing the required plots on a separate computer, thus allowing the user to continue with the slope stability analysis. However, the user should note that the batch-mode will only work successfully with devices that load the paper automatically. Thus in the case of a plotter, the batch-mode is not as useful since the user must insert a blank sheet of paper at the completion of ***every*** plot.

In order to ascertain the potential batch-mode capabilities of the **XPLOT** program, the example files, EX_1.GP1, EX_1.GP2 and EX_1.GP3 were printed and the following average times for each plot were noted*:

1. H.P. LaserJet printer . . . . . 2 minutes
2. EPSON FX-85 printer, high resolution . . . . . 15 minutes
3. EPSON FX-85 printer, low resolution . . . . . 5 minutes
4. H.P. 7475A Ink Plotter . . . . . 4 minutes

These times are intended only for a comparison between the various devices available for a hardcopy output of the slope geometry. In general, printing times will vary according to the complexity of the slope geometry and the speed of the computer, disk drives and printer.

**These times were measured in 1994.*

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APPENDIX A

EXAMPLE PROBLEM

This example is taken from the original problem presented in the STABL User Manual (JHRP 75-9, by Siegel, pp. 61-66) and concerns the assessment of the long term stability of a proposed cut in soft clay. The original slope and the proposed cut are shown in Fig. A-1. The reader should also note that an irregular bedrock surface and a groundwater table will be included in the analysis. The shear strength parameters ($c' = 500$ psf, $\varphi' = 14°$) do not vary significantly with depth, but due to dessication, tension cracks are expected to extend to a depth of 11 feet.

The soils in the slope will be modeled by two soil units, one for the intact clay and the other for the desiccated region. A simplified model of the slope geometry is presented in Fig. A-2 and the segment coordinates are tabulated in Table A-1. Please note that the surface boundary consists of five segments, and the single subsurface boundary is modeled by one segment. The phreatic surface is modeled using 9 coordinate points where the first 3 points coincide with the surface boundary.

Table A-1. Coordinates of Surface and Subsurface Segments

SEGMENT BOUNDARY COORDINATES

5 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	68.0	22.0	67.0	1
2	22.0	67.0	38.0	63.0	1
3	38.0	63.0	101.0	88.0	1
4	101.0	88.0	138.0	103.0	2
5	138.0	103.0	200.0	110.0	2

1 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	101.0	88.0	200.0	99.0	1

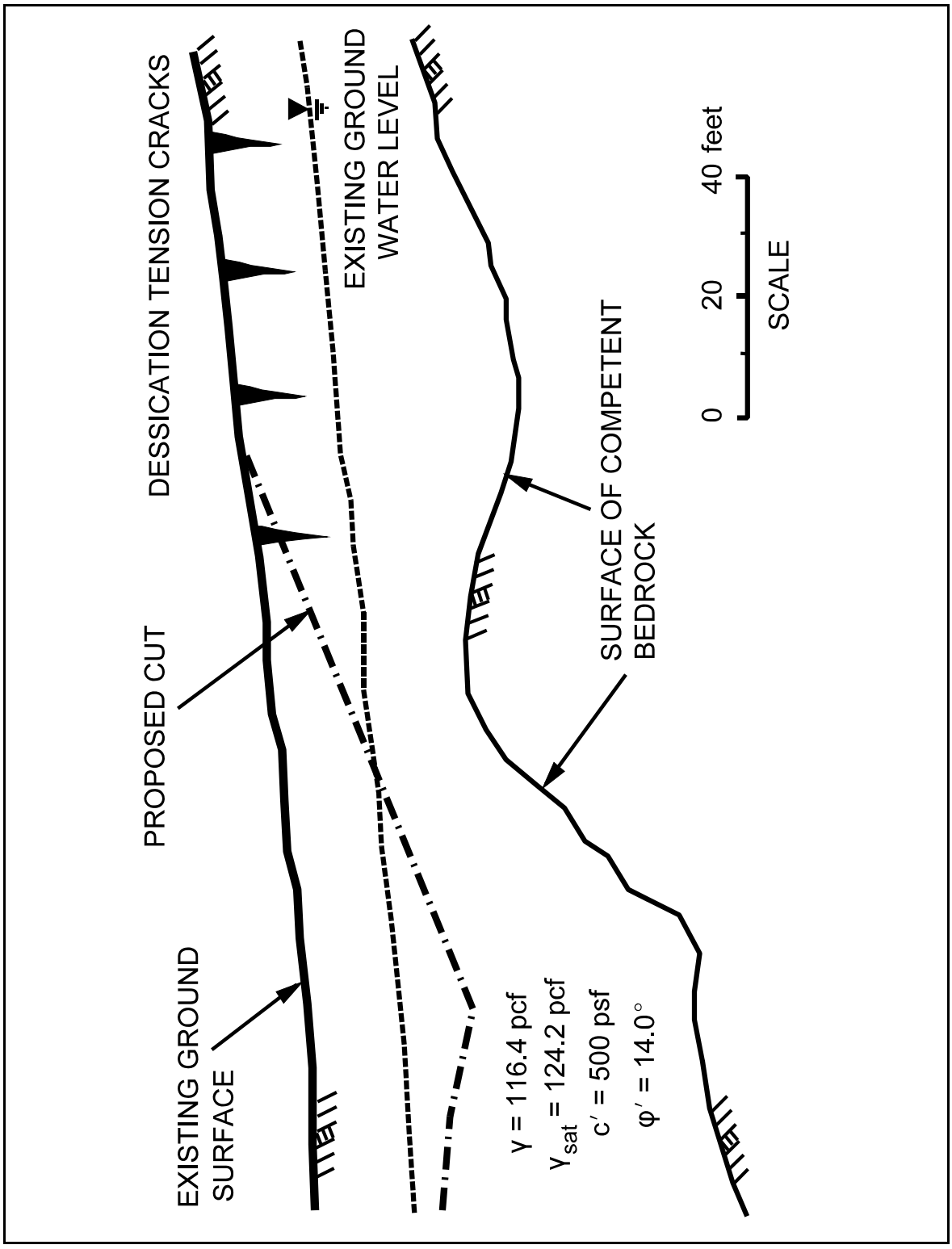

Fig. A-1. Example problem from STABL User Manual (after Siegel, 1975)

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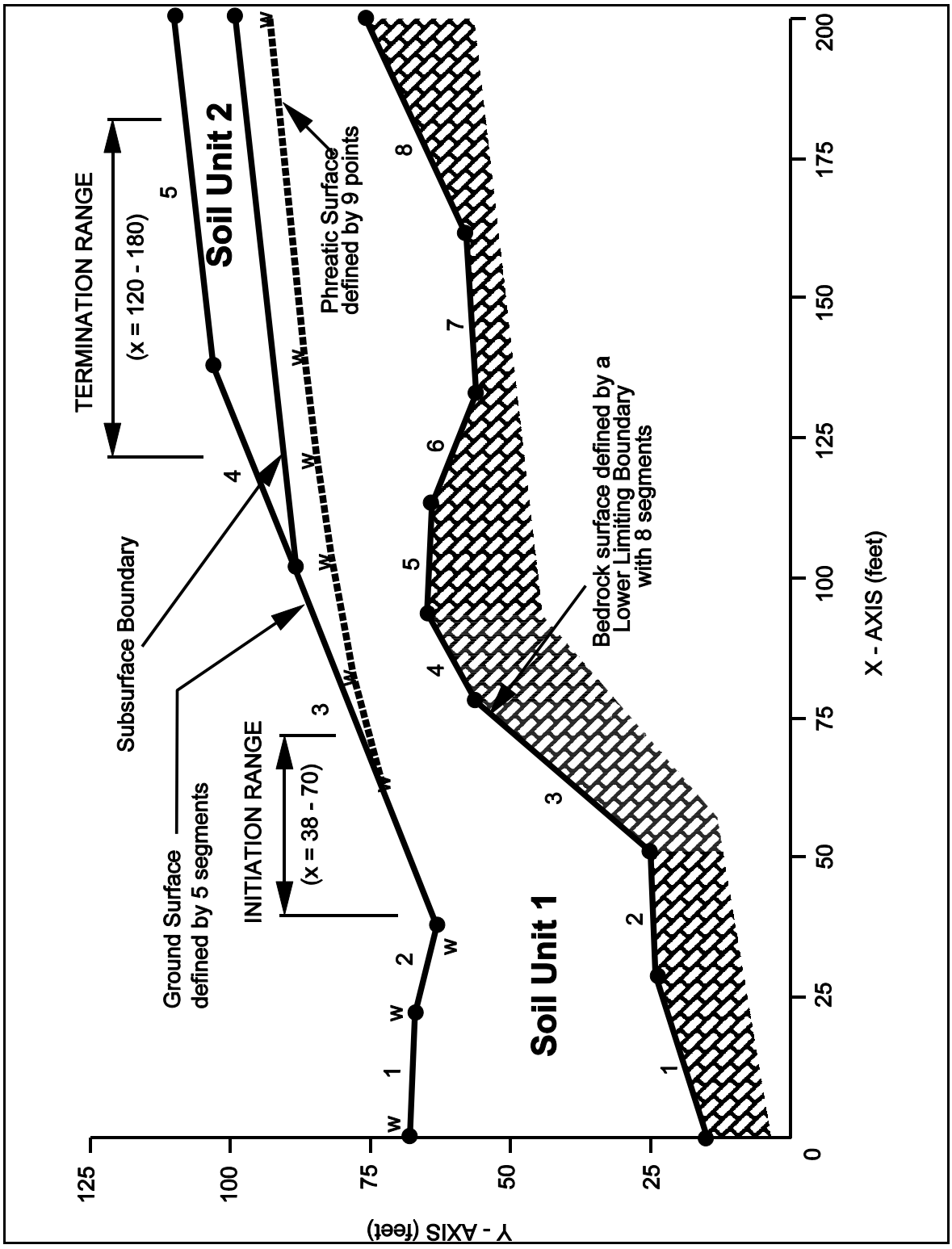

Fig. A-2. Development of slope geometry with **XSTABL**

Since the critical surface is not expected to pass through the bedrock, the undulating surface is modeled by a lower limiting boundary. Eight segments are specified for the limiting boundary and their coordinates are presented in Table A-2.

Table A-2. Coordinates for the lower limiting boundary segments

BOUNDARIES THAT LIMIT SURFACE GENERATION HAVE BEEN SPECIFIED

LOWER limiting boundary of 8 segments:

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)
1	.00	15.00	29.00	24.00
2	29.00	24.00	51.00	26.00
3	51.00	26.00	78.00	56.00
4	78.00	56.00	94.00	65.00
5	94.00	65.00	113.00	64.00
6	113.00	64.00	133.00	56.00
7	133.00	56.00	161.00	58.00
8	161.00	58.00	200.00	76.00

ANALYSIS

The defined slope consisting of the surface and subsurface boundaries, a phreatic surface, a lower limiting boundary and two soil units will be analyzed using circular, noncircular and block shaped surfaces. The analysis presented here is intended only to illustrate the approach required with **XSTABL** and is certainly not intended as a guideline for slope stability analysis.

For all options, 100 surfaces will be generated for a preliminary analysis. The location of the critical surface, i.e. failure surface with the lowest factor of safety, may then be determined on the basis of these 100 surfaces. After reviewing the results of the initial analysis, the user may decide to modify the surface generation parameters and seek a surface with a lower factor of safety.

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Circular Surfaces

The circular surfaces will be generated using ten foot segments between points located within the initiation and termination ranges, as shown in Fig. A-2. The surfaces will initiate from *ten* points equally spaced between x = 38 ft. and x = 70 ft. (initiation range). The first initiation point will be located at x = 38.0 with subsequent points located at equal increments of $\delta x = 4.667$ feet (i.e. (70 - 38) ÷ 9, spacings).

All surfaces will terminate within a range defined by x=120 and x=180 feet. The minimum horizontal elevation for surface generation is set at y=0.0 as it is unlikely to influence the analysis since a **lower limiting** boundary has been specified to simulate the rock surface. The upper and lower angular limits are both specified as zero. This results in the selection of the default angular limits of (β-5°) for the upper limit and -45° for the lower limit.

Table A-3 presents a summary of the ten most critical factors of safety determined for the cut-slope using the modified Bishop method of analysis. The input and output files (EX_1.IPT; EX_1.OPT and EX_1.GP?) for this analysis are included on the supplied program disk.

Table A-3. Summary of slope stability results using the circular surface option, file EX_1.IPT

The following is a summary of the TEN most critical surfaces

Problem Description : EX-1, Circular Search, FOS-BISHOP

	FOS (BISHOP)	Circle Center x-coord (ft)	y-coord (ft)	Radius (ft)	Initial x-coord (ft)	Terminal x-coord (ft)	Resisting Moment (ft-lb)
1.	1.397	59.52	219.21	157.69	38.00	169.78	1.582E+07
2.	1.410	71.21	187.08	124.03	45.11	165.01	1.165E+07
3.	1.438	61.69	152.37	92.45	38.00	139.86	7.046E+06
4.	1.473	72.63	151.21	87.33	48.67	145.96	6.408E+06
5.	1.488	49.76	215.89	153.34	38.00	155.60	1.228E+07
6.	1.513	88.29	149.35	83.10	59.33	158.61	6.810E+06
7.	1.522	50.94	248.44	184.27	41.56	168.24	1.611E+07
8.	1.527	42.38	287.85	224.89	38.00	176.46	2.159E+07
9.	1.544	97.18	141.87	77.04	62.89	165.35	7.188E+06
10.	1.545	84.34	148.53	81.02	59.33	152.25	5.836E+06

Block Shaped Surfaces

The central portion of the block-shaped surfaces will be generated from two search boxes located as shown in Fig. A-3. The parameters for the search boxes are:

Box No.	x-left (feet)	y-left (feet)	x-right (feet)	y-right (feet)	Width (feet)
1	40.00	50.00	48.00	50.00	8.00
2	120.00	65.00	140.00	75.00	20.00

The passive and active portions will be generated using eight-foot segments using the **RANKINE** (BLOCK2) option. Thus in the passive wedge, segments will be inclined at an angle of 59° (i.e. 45 + φ/2) CCW from the vertical. However for the active wedge, the segments will be inclined at an angle of 38° (i.e. 45 - φ/2) CW from the vertical within soil unit 1 and at 45° within the dessicated zone (φ=0°) defined by soil unit 2.

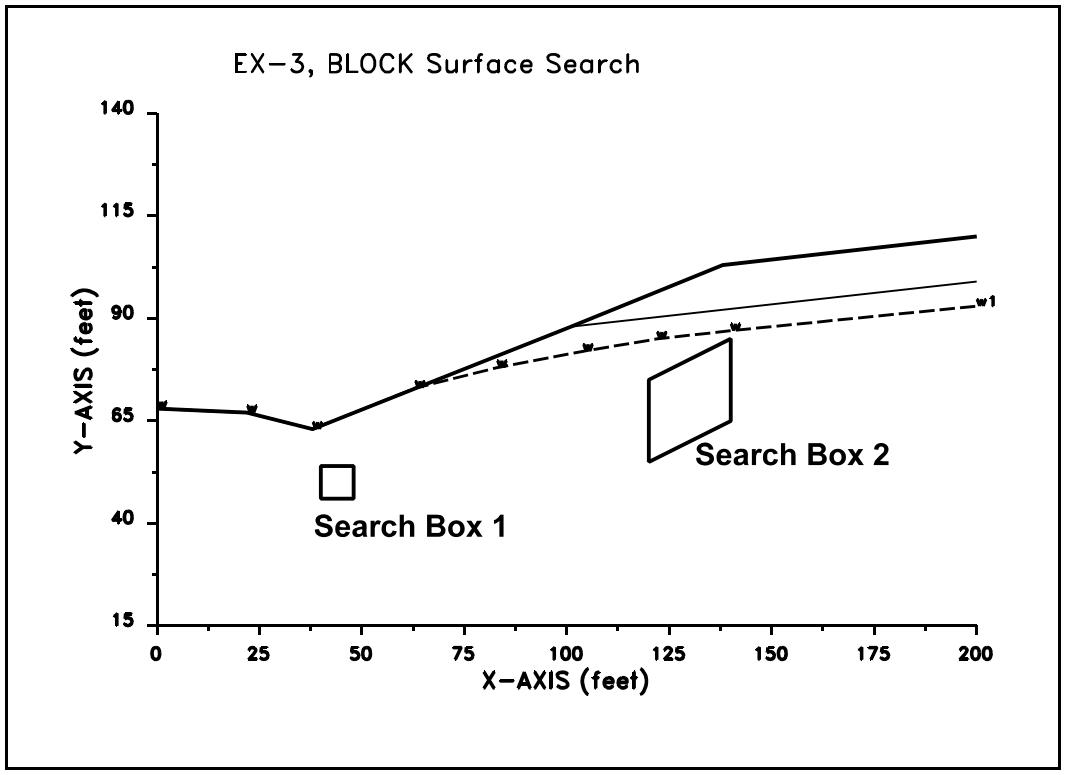

Fig. A-3. Location of search boxes for generation of block-shaped surfaces

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Table A-4, below, presents a summary of the ten most critical factors of safety determined for the cut-slope using the modified Janbu method of analysis. The input file for this analysis is included on the program disk as file EX_3.IPT.

Table A-4. Summary or slope stability results using the RANKINE surface option, file EX_3.IPT

The following is a summary of the TEN most critical surfaces

Problem Description : EX-3, BLOCK Surface Search

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.313	1.083	32.42	162.41	1.281E+05
2.	1.313	1.082	32.14	162.30	1.273E+05
3.	1.327	1.078	31.76	158.10	1.175E+05
4.	1.335	1.079	28.06	158.32	1.232E+05
5.	1.337	1.081	25.83	161.38	1.326E+05
6.	1.345	1.078	26.04	163.19	1.320E+05
7.	1.347	1.076	32.66	156.40	1.104E+05
8.	1.349	1.082	28.66	162.15	1.288E+05
9.	1.352	1.079	22.02	166.79	1.452E+05
10.	1.354	1.081	26.74	162.12	1.303E+05

Noncircular Surfaces

The noncircular surfaces will be generated using 25-foot segments between points located within the same initiation and termination ranges, as shown in Fig. A-2. Please note that a larger segment length will be used for this analysis in order to avoid kinematically inadmissable surfaces. The surfaces will initiate from *ten* points equally spaced between x=38 ft. and x=70 ft. (initiation range). The first initiation point will be located at x=38.0 with subsequent points located at equal increments of δx= 4.667 feet.

All surfaces will terminate within a range defined by x=120 and x=180 feet. The minimum horizontal elevation for surface generation is set at y=0.0 as it is unlikely to influence the analysis since a **lower limiting** boundary has been specified to simulate the rock surface. The upper and lower angular limits are both specified as zero. This results in the selection of the default angular limits of (β-5°) for the upper limit and -45° for the lower limit.

Table A-5 presents a summary of the ten most critical factors of safety determined for the cut-slope using the modified Janbu method of analysis. The input file for this analysis is included on the program disk as file EX_4.IPT.

Table A-5. Summary of slope stability results using the irregular surface option, file EX_4.IPT

The following is a summary of the TEN most critical surfaces

Problem Description : EX-4, Irregular Surf. Search, JANBU

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.365	1.062	41.56	149.81	8.473E+04
2.	1.369	1.060	41.56	155.14	9.751E+04
3.	1.383	1.060	38.00	144.41	8.780E+04
4.	1.383	1.063	45.11	158.13	9.452E+04
5.	1.393	1.063	45.11	145.21	7.842E+04
6.	1.401	1.059	41.56	147.23	8.650E+04
7.	1.406	1.060	45.11	151.50	8.767E+04
8.	1.412	1.058	38.00	144.64	7.654E+04
9.	1.419	1.066	38.00	144.95	8.171E+04
10.	1.426	1.058	38.00	147.01	7.700E+04

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Cracked Section Analysis

The cracked section for the example slope has been modeled as a *strength-less* soil unit that extended to a depth of 11 feet. In version 5 of **XSTABL**, it is now possible to include the anticipated depth of cracks directly into the slope. The same problem will now be reconsidered by using an 11-foot-deep cracked section instead of soil unit 2. The pertinent geometry and soil data for this case is given in Table A-6, below.

Table A-6. Data used for Cracked Section Analysis

```
 A CRACKED ZONE HAS BEEN SPECIFIED

     Depth of crack below ground surface = 11.00   (feet)
     Maximum depth of water in crack     =   .00   (feet)
     Unit weight of water in crack       = 62.40   (pcf)

Failure surfaces will have a vertical side equal to the
specified depth of crack and be affected by a hydrostatic
force according to the specified depth of water in the crack
```

Rather than perform all of the same analyses as presented for the previous example, this analysis used only the critical circular surface identified in Table A-3 for the two layer subsoil geometry. The circle was assigned using the coordinates of the circle-center and an initiation point located at x = 38.00 feet. The analysis was performed for:

(a) 11-foot-deep cracked section (file: EX_11.IPT).

(b) 11-foot-deep cracked section, with 6 feet of water (file: EX_12.IPT).

A summary of the analysis using different procedures for calculating the FOS is presented in Table A-7. The EX_1S.IPT file includes the critical circular failure surface along with the strengthless soil unit 2, as used for the original analysis.

Table A-7. Comparison of FOS Results for Cracked Sections

METHOD OF ANALYSIS	DATAFILE		
	EX_1S.OPT	EX_11.OPT	EX_12.OPT
Simplified Bishop	1.397	1.536	1.509
Spencer	1.388	1.535	1.514
GLE, Half-Sine	1.383	1.535	1.513

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APPENDIX B

FORMAT OF INPUT DATA FILE

The input data file, *.IPT, that is used for the slope stability analysis is assembled according to the unique format discussed in this appendix. It closely follows the format used for defining the input data file for STABL4, as described in the STABL User Manual. However unlike the rigid formatting requirements of STABL4, **XSTABL** is capable of reading the input file with a free format convention that requires the separation of data values by a minimum of one blank space. Due to these overall similarities, most files that may have been created for use with STABL4 can also be used with **XSTABL** without requiring any modifications. However, since the new option SURB2 replaces the older STABL4 option SURBIS, such files will have to be modified for use with **XSTABL**.

The overall format of the input data file consists of a capitalized, keyword descriptor (e.g. PROFIL, SOIL, etc.) followed by a block of numeric data. This numeric data is described for the thirteen possible keywords below:

Slope Geometry

Surface and Subsurface Boundaries

PROFIL
Title
Total number of segments
Number of surface segments

The following five values are repeated for each segment, starting with the surface boundary segments first:

X coordinate of left end of segment	(feet or meters)
Y coordinate of left end of segment	(feet or meters)
X coordinate of right end of segment	(feet or meters)
Y coordinate of right end of segment	(feet or meters)
Soil unit number for soil beneath segment	

Cracked Section

Cracked Section Data

CRACK

Depth of Cracked Section	(feet or meters)
Depth of Water in Crack	(feet or meters)
Unit Weight of Water in Crack	(pcf or kN/m^3)

SOIL PROPERTIES

Soil Property Data (isotropic)

SOIL

Number of soil units

Repeat for all soil units :

Moist unit weight	(pcf or kN/m^3)
Saturated unit weight	(pcf or kN/m^3)
c -- Isotropic strength intercept	(psf or kPa)
φ -- Isotropic strength angle	(deg)
Ru -- Pore pressure ratio	
Constant Pore pressure	(psf or kPa)
Water Surface Index	

Reinforced Slope

REINF

Required Factor of Safety

Elevation of resultant force for presumed reinforcement stress distribution (feet or meters)

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Nonlinear Mohr-Coulomb Strength Envelope

NLSOIL

Number of soil units with curved M-C envelope

For each soil unit number, repeat:

Number of points defining (σ, τ) curve

For each point on the curve, specify:

Effective stress, σ	(psf or kPa)
and shear strength, τ	(psf or kPa)

Undrained Soil Strength

UNDRAINED

Number of soil units with undrained strengths

Soil Unit Number of soils with undrained strength

Anisotropic Strength

ANISO

Number of anisotropic soil types

Repeat for number of anisotropic soil types:

Soil Unit Number

Number of discrete angular strength ranges

Repeat for each strength range:

Counterclockwise direction limit	(deg)
Strength intercept	(psf or kPa)
Strength angle	(deg)

Phreatic and Piezometric Surfaces

WATER
Number of water surfaces defined
Unit weight of water (pcf or kN/m^3)

For each water surface, repeat:
Number of points defining the water surface
(POSITIVE for a phreatic surface, and
NEGATIVE for a piezometric surface)

Repeat for each point on the water surface:
X coordinate of point on water surface (feet or meters)
Y coordinate of point on water surface (feet or meters)

Pore Pressure Grid

PWGRID
Number of points defining pore pressure grid

Repeat for each point:
X coordinate of point (feet or meters)
Y coordinate of point (feet or meters)
Pore water pressure at location (x, y) (feet or meters)

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SLOPE ANALYSIS

Circular Surface Search

CIRCL2 for modified Bishop Analysis
CIRCLE for modified Janbu Analysis

Number of initiation points
Number of surfaces to be generated from each initiation point
X coordinate of leftmost initiation point (feet or meters)
X coordinate of rightmost initiation point (feet or meters)
X coordinate of left termination limit (feet or meters)
X coordinate of right termination limit (feet or meters)
Minimum elevation of surface development (feet or meters)
Length of segments defining surfaces (feet or meters)
Upper directional limit for surface initiation (deg)
Lower directional limit for surface initiation (deg)

Irregular Surface Search

RANDOM
Number of surfaces to be generated from each init. point
X coordinate of leftmost initiation point (feet or meters)
X coordinate of rightmost initiation point (feet or meters)
X coordinate of left termination limit (feet or meters)
X coordinate of right termination limit (feet or meters)
Minimum elevation of surface development (feet or meters)
Length of segments defining surfaces (feet or meters)
Upper directional limit for surface initiation (deg)
Lower directional limit for surface initiation (deg)

Block Surface Search

BLOCK2 for Rankine assumption
BLOCK for irregular active and passive portions

Total number of surfaces to be generated
Number of search boxes
Length of segments defining surfaces (feet or meters)

Repeat for each search box:
- X coordinate of left end of centerline of box (feet or meters)
- Y coordinate of left end of centerline of box (feet or meters)
- X coordinate of right end of centerline of box (feet or meters)
- Y coordinate of right end of centerline of box (feet or meters)
- Length of vertical side of box (feet or meters)

Specific Circular Failure Surface

SURF2
x coordinate of center of circle (feet or meters)
y coordinate of center of circle (feet or meters)
x coordinate of first initiation point (near toe of slope) (feet or meters)
Segment length (feet or meters)

Specific Noncircular Failure Surface

SURFAC
Number of points defining the failure surface

Repeat for each point:
- X coordinate of point on failure surface (feet or meters)
- Y coordinate of point on failure surface (feet or meters)

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Earthquake Loads

EQUAKE
Earthquake coefficient for horizontal acceleration
Earthquake coefficient for vertical acceleration

Boundary Loads

LOADS
Number of boundary loads

Repeat for each boundary load:

X coordinate of left end of boundary load	(feet or meters)
X coordinate of right end of boundary load	(feet or meters)
Intensity of boundary load	(psf or kPa)
Angle of inclination of boundary load	(deg)

Limiting Boundaries

LIMIT
Total number of limiting boundary segments
Number of lower limiting boundary segments

Repeat for all segments, beginning with the LOWER segments:

X coordinate of left end of segment	(feet or meters)
Y coordinate of left end of segment	(feet or meters)
X coordinate of right end of segment	(feet or meters)
Y coordinate of right end of segment	(feet or meters)

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APPENDIX C

LIST OF INPUT DATA ERRORS

Before performing the slope stability analysis, **XSTABL** checks the input data for possible errors. If an error is encountered, an error number and a message is written to the output file. However, if the program is unable to locate the file XSTABL.ERR, only an error number will be written to the output file. In such cases, the user should consult the appropriate error message listed in this appendix.

Soil Properties

ERROR 1
An attempt has been made to perform a stability analysis without defining the ISOTROPIC soil parameters. The requested analysis cannot be completed without these soil parameters. Please specify the necessary ISOTROPIC soil parameters and then retry the analysis.

ERROR 2
For defining ANISOTROPIC soil parameters, a minimum of two direction ranges must be specified. The first range ALWAYS starts at -90° CW and the last (or second) range terminates at +90° CCW. Please check your input data for ANISOTROPIC parameters.

ERROR 3
In defining the ANISOTROPIC parameters, the specified direction ranges are NOT in the required counterclockwise sequence. This sequence should include a total of 2-10 ranges that start at -90° CW and conclude at +90° CCW. Please check the input ANISOTROPIC data.

ERROR 4
In defining the ANISOTROPIC parameters, the last range must finish at +90° CCW from the horizontal. The input data does NOT include this last required direction range. Please check the ANISOTROPIC data before retrying the stability analysis.

Non-linear Mohr-coulomb

ERROR 5
In defining the Non-linear MOHR-COULOMB parameters, a minimum of two data points (and a maximum of twenty) must be defined for the normal and shear stresses. Please check the input data for this option to ensure that at least TWO, and not more than TWENTY, are specified.

ERROR 6
In defining the Non-linear MOHR-COULOMB parameters, the normal/shear stress combination for each data point must specified such that they increase sequentially. Please check input data to ensure that the generated M-C curve has a continuously positive gradient.

ERROR 7
The normal effective stress on the base of a slice was found to be outside the range of stresses used to define the curved Mohr-Coulomb envelope. The value of this normal stress and the soil unit number are reported below. Please expand the range of the NLMC data.

Geometry / boundaries

ERROR 8
The above boundary segment is not to the right of the segments specified prior to it. The points defining the boundary segment must be specified in a sequential left to right order. Thus the surface starts from the LEFT side and finishes on the RIGHT side.

ERROR 9
The program has detected an error with the ordering of one of the above subsurface boundaries. It appears that the boundary, shown below, does NOT completely lie above the next boundary, as required by the program. Check this sequence before retrying the analysis.

ERROR 10
The SOIL UNIT for the above boundary has been omitted from the input soil parameter data or the above surface/subsurface boundary segment. Please check the data input for the soil parameters for "missing" soil unit(s) before retrying the stability analysis.

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ERROR 11
The combined TOTAL number of surface and boundary segments exceeds the allowable maximum of 100 segments. Please modify the subsurface geometry such that fewer boundary segments are specified before trying the analysis again.

ERROR 12
The x-coordinates for the above surface segment indicate that the segment is VERTICAL. Such vertical segments should not be specified. Please "increase" the x-coordinate of the right-end of the segment to eliminate this "verticality" before repeating the analysis.

Water Surfaces

ERROR 13
The above water surface point is not to the right of the points specified prior to it. The points defining the water surface must be specified in a sequential left to right order. Thus the surface starts from the LEFT side and finishes on the RIGHT side.

ERROR 14
A water surface index number specified for a soil unit is greater than the TOTAL number of water surfaces specified. It is possible that either an insufficient number of water surfaces have been specified or a wrong number may have been used for the soil unit.

ERROR 15
A value of the pore water pressure coefficient, Ru, has been specified as greater than ONE. Typically, this value is usually less than or equal to about 0.5, and larger values are likely give numerical problems. Please check your data before trying the analysis again.

ERROR 16
Water or piezometric surfaces AND pore water pressures at discrete points have been included in the input data. You must discard one of these, i.e. you may only use a pore pressure grid OR water/ piezometric surfaces.....not both at the same time.

ERROR 17
Pore water pressures have been specified at discrete points. However, there are either insufficient number of points (a minimum of four required), or the points are not located within the defined slope geometry. Please check the coordinates of the pore pressure locations

Loads

ERROR 18
One of the specified boundary loads is located outside the bounds of the slope, as defined by the surface boundary segments. Please check the specified locations of the assigned boundary loads to ensure that these are properly included in the slope analysis.

ERROR 19
In specifying the BOUNDARY LOADS, the x-coordinates defining the horizontal extent of the above surcharge boundary load have not been specified in the required left-to-right sequence. The left side of the loaded area must precede the right side. Please check.

ERROR 20
The above surcharge BOUNDARY LOAD is not to the right of all the loads specified prior to it or possibly overlaps one or more of them. These boundary loads must be specified left to right and are not allowed to overlap. Please check for this required sequence.

SURFACE SEARCH - Circular/irregular

ERROR 21
One of the x-coordinates of the initiation range lies to the LEFT of the defined ground surface profile. This range must EXIST within the defined geometry. Please make sure that the value of the left point is greater than the left x-coordinate of the first surface boundary.

ERROR 22
It appears that first initiation point does NOT correspond to the LEFT side of the initiation range. These two values must be specified in a left-to-right sequence. Please check the data for surface generation using either circular or non-circular surfaces.

ERROR 23
One of the x-coordinates of the initiation range lies to the RIGHT of the defined ground surface profile. This range must EXIST within the defined geometry. Please make sure that the value of the right point is less than the right x-coordinate of the last surface boundary.

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ERROR 24
One of the x-coordinates of the termination range lies to the RIGHT of the defined ground surface profile. This range must EXIST within the defined geometry. Please make sure that the value of the right point is less than the right x-coord of the last surface boundary.

ERROR 25
It appears that the first termination point does NOT correspond to the LEFT side of the termination range. These two values must be specified in a left-to-right sequence. Please check the data for surface generation using either circular or non-circular surfaces.

ERROR 26
The right limit of the initiation range is located beyond the right limit of the termination range. Due to this overlap, surfaces that start from the initiation range cannot extend into the specified termination range. Please check the initiation/termination ranges.

ERROR 27
An initiation point is located below the imposed elevation depth limitation. Either the initiation range or the depth limitations must be changed to enable the successful generation of trial failure surfaces. Please correct the data before retrying the analysis.

ERROR 28
In automatically generating a failure surface, it has been found that more than 100 points are needed to define this surface. The program is limited to a maximum of 100 points. To meet this criterion, please INCREASE the specified length of the line segments.

ERROR 29
The program has made 200 attempts to generate a single trial failure surface. It is possible that the search limitations are either too restrictive, or they actually prevent successful generation of a trial failure surface. Check and revise the search limitations.

ERROR 30
The angle specified as the LOWER angular limit for surface generation is larger than the angle specified as the UPPER limit. This is not correct. Please check the data for a possible reversal of these values before retrying the analysis.

BLOCK SURFACES - Search

ERROR 31
An error was detected for the coordinates specified for the left and right centers of a SEARCH BOX. The left-side points MUST be specified before the right-side points. Please check the input data before attempting to retry the stability analysis.

ERROR 32
The above SEARCH BOX and the one specified before it are not properly ordered, or they overlap. All boxes must be specified in toe-to-crest order and the boxes are not allowed to overlap. Please check the input data before attempting to retry the analysis.

ERROR 33
The above SEARCH BOX is wholly or partially above the defined ground surface. Each box must be defined TOTALLY below the ground surface to allow successful generation of block failure surface. Please check the input data before attempting to retry the analysis.

ERROR 34
It is not possible to complete the active portion of the failure surface from part of or all of the last SEARCH BOX specified. The last box specified must allow sufficient "room" for generating the final portion of the block surface.

ERROR 35
It is not possible to complete the passive portion of the failure surface from part of or all of the first SEARCH BOX specified. The first box specified must allow sufficient "room" for generating the initial portion of the block surface.

ERROR 36
In automatically generating a block failure surface, it has been found that more than 100 points are needed to define this surface. The program is limited to a maximum of 100 points. To meet this criterion, please INCREASE the length of the line segments.

ERROR 37
The program has made 200 attempts to generate a single block trial surface. The search limitations are either too restrictive or they actually prevent successful generation of a trial failure surface. Check and revise the search limitations before retrying.

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ERROR 38
The program calculated a point for the PASSIVE wedge that is outside the defined slope geometry. The analysis will continue, but the user should adjust the search box or slope geometry to allow a passive wedge to be formed from all points within first box.

ERROR 39
The program calculated a point for the ACTIVE wedge that is outside the defined slope geometry. The analysis will continue, but the user should adjust the search box or slope geometry to allow an active wedge to be formed from all points within last box.

SPECIFIC SURFACE

ERROR 40
The above trial surface point is out-of-sequence with respect to the points specified prior to it. Points defining the trial surface must be specified in a sequential toe-to-crest order. Please check the sequence of the specific surface data before retrying the analysis.

ERROR 41
One of the points specifying the above trial surface is OUTSIDE the extent of the defined ground surface profile. All points defining a trial failure surface must be within the horizontal extent of the defined ground surface. Please check coordinates before retrying.

ERROR 42
The x-coord of the first point lies to the LEFT of the defined ground surface profile. This value must EXIST within the defined slope geometry. Please make sure that the x-coord of this initial point is to the RIGHT of the left-end of the first surface segment.

ERROR 43
On the basis of the information provided for the generation of a single circular surface, some coordinates were calculated OUTSIDE the range of the defined slope geometry. Please check the input data, or review the slope geometry using the F2 option.

ERROR 44
The segment length for the requested failure surface(s) has been set as 0.0 (zero). The analysis has been terminated as the problem cannot be analyzed using a zero segment length. Please check the slope geometry data before repeating analysis.

ERROR 45
In automatically generating a SPECIFIC circular failure surface, more than 100 points are needed to define this surface. The program is limited to a maximum of 100 points. To meet this criterion, please INCREASE the length of the line segments.

GENERAL ERRORS - all surfaces

ERROR 46
The specified, or calculated, trial failure surface extends above the ground surface of the defined slope geometry. Please check the coordinates of the surface boundary or the data for the specified failure surface for possible errors before repeating the analysis.

ERROR 47
The coordinates for the above failure surface do not sequentially progress from toe-to-crest, as required for a successful analysis. Check either the specified x-coords for the initiation/termination ranges or the coordinates of the specific failure surface.

ERROR 48 (WARNING)
Negative effective stresses were calculated at the base of a slice. This warning is usually reported for cases where slices have low self weight and a relatively high "c" shear strength parameter. In such cases, this effect can only be eliminated by reducing the "c" value.

ERROR 49 (WARNING)
Negative effective stresses were calculated due to relatively HIGH pore water pressures. XSTABL will automatically limit the magnitude of such pore pressures such that the calculated shear strength is always greater than, or equal, to zero.

ERROR 50 (WARNING)
This warning is usually reported for cases where slices near the toe of the slide mass have steep, negative base angles. Generally, this error condition can be avoided by "raising" the lower angular limit boundary to prevent generation of such deep failure surfaces.

ERROR 51
One or both of the values specified for the clipped half-sine function are outside the acceptable range. These values must be within a range that extends between 0 and 1.0. Please adjust the clipping values before trying the analysis again.

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ERROR 52
The user-specified GLE function for the interslice force angles is not correct. The normalized x-coord and the amplitude of the function must be greater than or equal to zero AND less than or equal to 1.0. Values outside this range cannot be accommodated by XSTABL.

ERROR 53
Only ONE point has been specified for the user-specified GLE function for the interslice force angles. A minimum (complete) function should consist of at least two points that have normalized x-coordinates of 0.0 (toe) and 1.0 (crest). Please specify the function again.

ERROR 54
The user-specified GLE function for the interslice force angles has not been specified for the entire surface. A complete function should range between normalized x-coordinates of 0.0 (toe) and 1.0 (crest). Please supply a complete function with at least two values.

ERROR 55
The user-specified function of the thrust line location for the Janbu GPS procedure is not correct. The normalized x-coord and the thrust line ratio must be greater than or equal to zero AND less than or equal to 1.0. Values outside this range cannot be accommodated by XSTABL.

ERROR 56
Only ONE point has been specified for thrust line location for the Janbu GPS procedure. A minimum (complete) function should consist of at least two points that have normalized x-coordinates of 0.0 (toe) and 1.0 (crest). Please specify the function again.

ERROR 57
The function describing the thrust line location for the Janbu GPS procedure has not been specified for the entire surface. A complete function should range between normalized x-coordinates of 0.0 (toe) and 1.0 (crest). Please supply a complete function for the analysis.

ERROR 58
The user specified interslice force angle should range between plus or minus 90 degrees only. For numerical reasons, the absolute value must be less than 90 degrees. Please check your analysis and provide an appropriate value of the interslice force angle.

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APPENDIX D

METHODS OF ANALYSIS

The **XSTABL** program uses the method of slices in conjunction with the limit equilibrium procedure to calculate the factor of safety for a slope. This approach requires that the potential slide-mass be divided into n smaller slices as shown in Figure D.1.

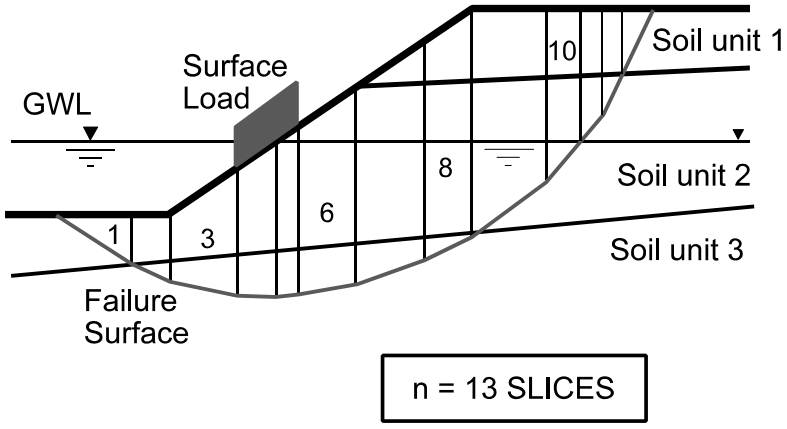
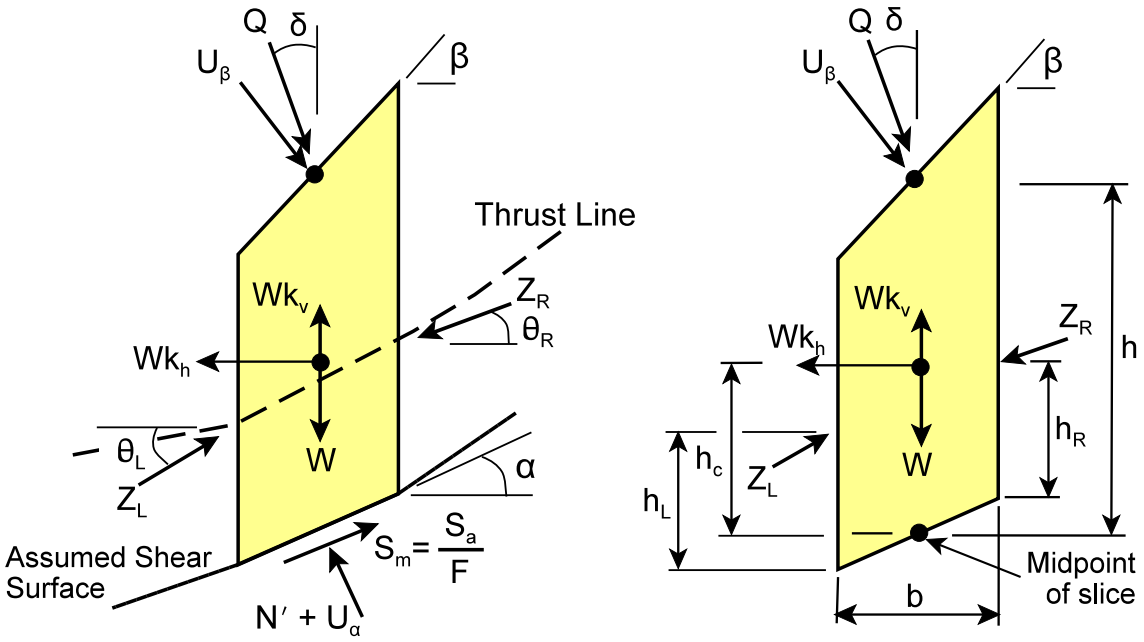


Fig. D-1. Division of potential sliding mass into slices

Each slice is affected by a general system of forces as shown in Figure D.2. The thrust line indicated in the figure connects the points of application of the interslice forces, Z_i. The location of this thrust line may be assumed, as in the rigorous Janbu method (Janbu, 1973), or its location may be determined using a rigorous method of analysis that satisfies complete equilibrium. The popular simplified methods of analysis neglect the location of the interslice force because complete equilibrium is not satisfied for the failure mass.

For this system, there are (6n - 2) unknowns as listed in Table D.1. Also, since only four equations can be written for the limit equilibrium conditions for the system, the solution is statically indeterminate. However, a solution is possible providing the number of unknowns can be reduced by making some simplifying assumptions. One of the common assumptions is that the normal force on the base of the slice acts at the midpoint, thus reducing the number of unknowns to (5n - 2). This then requires an additional (n-2) assumptions to make the problem determinate.



F	=	factor of safety	Z_L	=	left interslice force
S_a	=	available strength	Z_R	=	right interslice force
	=	$C + N' \tan\varphi$	θ_L	=	left interslice force angle
S_m	=	mobilized strength	θ_R	=	right interslice force angle
U_α	=	pore water force	h_L	=	height to force Z_L
U_β	=	surface water force	h_R	=	height to force Z_R
W	=	weight of slice	α	=	inclination of slice base
N′	=	effective normal force	β	=	inclination of slice top
Q	=	external surcharge	b	=	width of slice
k_v	=	vertical seismic coefficient	h	=	average height of slice
k_h	=	horizontal seismic coefficient	h_{eq}	=	height to centroid of slice

Fig. D.2 Forces acting on a typical slice

There are many limit equilibrium formulations available for slope stability analysis, each one implementing its unique assumptions in order to obtain a solution. A General Limit Equilibrium (GLE) formulation (Fredlund et al., 1981, Chugh, 1986) can be developed to encompass most of the assumptions used by the various methods and may be used to analyze circular and noncircular failure surfaces. In view of this universal applicability, the GLE has become one of the most popular methods as its generalization offers the ability to model a discrete version of the Morgenstern-Price (1965) procedure via the function used to describe the distribution of the interslice force angles. The method can be used to satisfy either force and moment equilibrium, or if required, just the force equilibrium conditions. With this approach, Spencer's method (Spencer, 1973) can be implemented directly via the use of a constant interslice force function.

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Table D.1. Equations and unknowns associated with the Method of Slices

Equations	Condition
n	Moment equilibrium for each slice
2n	Force equilibrium in two directions (for each slice)
n	Mohr-Coulomb relationship between shear strength and normal effective stress
4n	**Total number of equations**
Unknowns	
1	Factor of Safety
n	Normal force at base of each slice, $\Delta N'$
n	Location of normal force, $\Delta N'$.
n	Shear force at base of each slice, ΔS
n - 1	Interslice force, Z
n - 1	Inclination of interslice force, θ
n - 1	Location of interslice force (line of thrust)
6n - 2	**Total number of unknowns**

The GLE procedure relies on the selection of an appropriate function that describes the variation of the interslice force angles to satisfy complete equilibrium. In contrast, Janbu's General Procedure of Slices (GPS) assumes the location of the thrust line and then proceeds to calculate the interslice force angles required to satisfy complete equilibrium. Intuitively, it is perhaps easier to assume the location of the thrust line, but in reality, the computations are very sensitive and can often lead to numerical problems such as the failure to converge to a successful solution of the FOS.

The main difficulty in using the GLE procedure is related to the requirement that the user verify the reliability and "reasonableness" of the calculated factor of safety. This additional complexity prevents the general use of the GLE method for automatic search procedures that attempt to identify the critical failure surface. However, single failure surfaces can be analyzed and the detailed solution examined for reasonableness. For judging the viability of the reported factor of safety values, a substantially higher level of familiarity and understanding of the underlying assumptions, algorithms and objectives is now required for practical problems.

Conversely, the simplified Bishop (1955) and Janbu (1957, 1973) methods are popular because a factor of safety value can be quickly calculated for most surfaces. However, these methods do not satisfy complete force and moment equilibrium and thus different values of the factor of safety will be calculated in comparison with the methods that satisfy conditions of complete equilibrium. For circular failure surfaces, the factor of safety computed by Bishop's method is usually greater than the value from Janbu's formulation. Bishop's FOS value is also generally within 5 percent of the FOS value that may be calculated using a more rigorous approach such as the GLE method. So for the analysis of circular failure surfaces, the simplified Bishop's method is strongly recommended for analysis. However, Janbu's method is more flexible as the formulation may be applied for evaluating the FOS for circular and noncircular surfaces.

The GLE method and the simplified Bishop and Janbu methods are implemented in **XSTABL** version 5. As these methods may lead to a different factor of safety (FOS) for the same surface, it is important that the user understand details concerning the derivation of the FOS expressions. The complete equations for these methods, as well as Janbu rigorous General Procedure of Slices (GPS) are presented next.

D.1 The Generalized Limit Equilibrium (GLE) Method

The GLE method is an extension of Spencer's (1973) procedure, generalized by Chugh (1986) and then implemented into version 5 of **XSTABL** in 1994. The GLE method adopts a function, $\theta_i = \lambda \cdot f(x_i)$ to assign the interslice force angle on the right-hand side of slice i, as shown in Figure D.2. The function, $f(x_i)$, ranges between 0 and 1 and essentially represents the shape of the distribution used to describe the variation of the interslice force angles, as shown in Figure D.3. The adoption of this function provides (n-1) assumptions regarding the interslice force angles and the λ value is an additional unknown, which is introduced such that there are the requisite (n-2) unknowns, as discussed earlier. The selected interslice force angle function, f(x), can be set as a constant (i.e. f(x) = 1.0) to emulate Spencer's procedure, or any other shape for a discrete version of a Morgenstern-Price solution.

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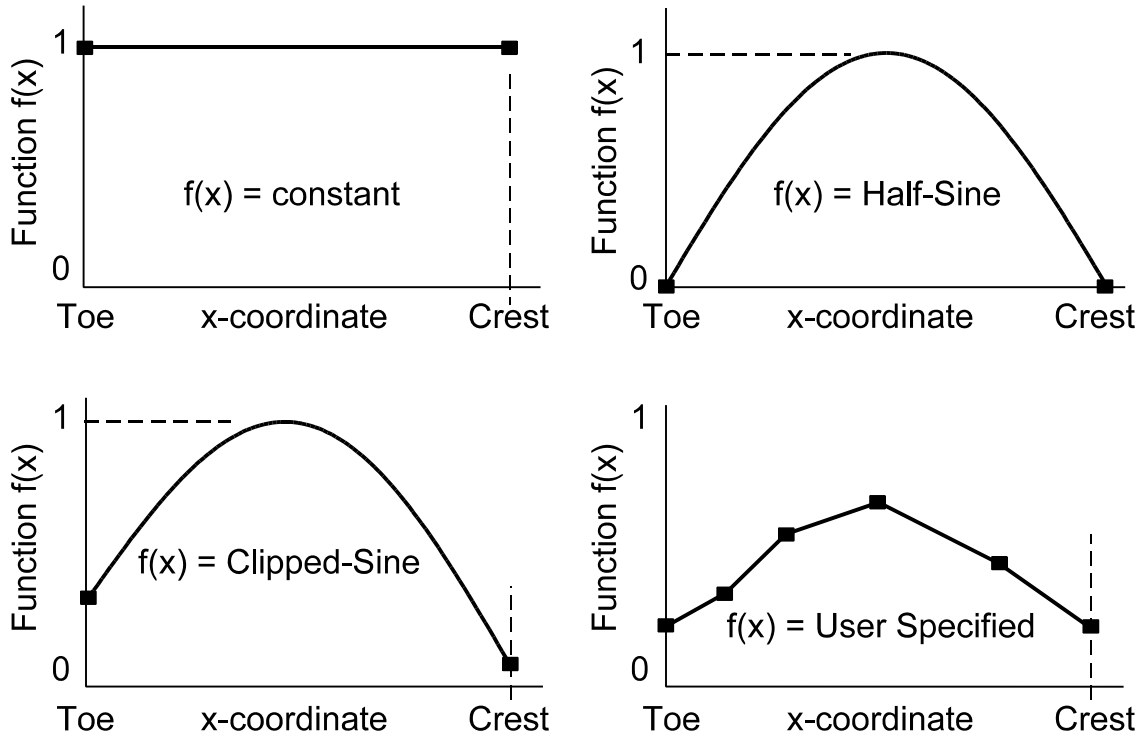

Fig. D-3. Examples of functions used to describe the variation of interslice force angles

The adopted formulation uses a discrete form of the continuous function, f(x), to calculate the function at each interslice boundary, using the angles labeled θ_L and θ_R for the left and right vertical sides of the slice, as shown in Figure D.2. Thus for a typical interslice boundary, $\theta_R = \lambda\ f(x)$, where x is the x-coordinate of the right side of the selected slice. The **XSTABL** implementation of the function, f(x), uses a function that is normalized with respect to the lateral (horizontal) extent of the failure surface. As the interslice force angle for the left side of the first slice (at the toe) and the right side of the last slice (at the crest) is assumed to be zero, this lateral extent is assumed to range *between* the first and last interslice boundary.

Force Equilibrium

The GLE method assumes that the interslice resultant force, Z_L and Z_R, are inclined at θ_L and θ_R on the left and right side of each slice, as shown in Figure D.2. These interslice forces are *total* forces as the hydrostatic component along the interslice boundaries is not considered separately. Interslice hydrostatic forces can be considered in an analysis, but are difficult to implement for layered soils and multiple water surfaces. If force equilibrium is considered in a direction parallel to the base of each slice:

$$\begin{aligned} & S_m + Z_L\cos(\alpha - \theta_L) - Z_R\cos(\alpha - \theta_R) \\ & - W(1 - k_v)\sin\alpha - Wk_h\cos\alpha \\ & - U_\beta\sin(\alpha - \beta) - Q\sin(\alpha - \delta) = 0 \end{aligned} \qquad \textbf{(D.1)}$$

and if the Mohr-Coulomb strength criterion is adopted such that the mobilized strength,

$$S_m = \frac{S_a}{F} = C_m + N'\tan\varphi_m \qquad \textbf{(D.2)}$$

where

$$C_m = \frac{C}{F} \qquad \text{and} \qquad \tan\varphi_m = \frac{\tan\varphi}{F} \qquad \textbf{(D.3)}$$

Then by substituting Eq. D.2 into D.1, the following expression is derived:

$$\begin{aligned} N'\tan\varphi_m = {} & Z_R\cos(\alpha - \theta_R) - Z_L\cos(\alpha - \theta_L) \\ & + W[(1 - k_v)\sin\alpha + k_h\cos\alpha] - C_m \\ & + U_\beta\sin(\alpha - \beta) + Q\sin(\alpha - \delta) \end{aligned} \qquad \textbf{(D.4)}$$

Next force equilibrium is formulated in a direction normal to the base of the slice:

$$\begin{aligned} & N' + Z_R\sin(\alpha - \theta_R) - Z_L\sin(\alpha - \theta_L) \\ & + U_\alpha - W(1 - k_v)\cos\alpha + Wk_h\sin\alpha \\ & - U_\beta\cos(\alpha - \beta) - Q\cos(\alpha - \delta) = 0 \end{aligned} \qquad \textbf{(D.5)}$$

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By substituting Eq. D.5 into D.4, the following force equilibrium equation may be formulated:

$$\begin{aligned} Z_R \;=\; & A_1 Z_L [\, \cos(\alpha - \theta_L) + \sin(\alpha - \theta_L)\tan\varphi_m \,] \\ & + A_1 \Big[\, W\cos\alpha\,(1 - k_v)(\tan\varphi_m - \tan\alpha) \\ & + C_m - U_\alpha \tan\varphi_m - W k_h (1 + \tan\varphi_m \tan\alpha)\cos\alpha \\ & + U_\beta\, [\cos(\alpha - \beta)\tan\varphi_m - \sin(\alpha - \beta)] \\ & + Q\, [\cos(\alpha - \delta)\tan\varphi_m - \sin(\alpha - \delta)] \,\Big] \end{aligned} \qquad \textbf{(D.6)}$$

where the factor A_1 is given by:

$$A_1 \;=\; \frac{1}{\cos(\alpha - \theta_R)\,[\,1 + \tan\varphi_m \tan(\alpha - \theta_R)\,]} \qquad \textbf{(D.7)}$$

Moment Equilibrium

The conditions for moment equilibrium are satisfied by taking moments of all forces about the midpoint of the base of the slice, as shown in Figure D.2, generating the following expression:

$$\begin{aligned} & Z_L \cos\theta_L \,[h_L - \frac{b}{2}\tan\alpha] + Z_L \frac{b}{2}\sin\theta_L \\ & + Z_R \frac{b}{2}\sin\theta_R - Z_R \cos\theta_R \,[h_R + \frac{b}{2}\tan\alpha] \\ & - W k_h h_c + U_\beta h \sin\beta + Q h \sin\delta \;=\; 0 \end{aligned} \qquad \textbf{(D.8)}$$

Next the above expression is simplified to determine the location of the interslice force, h_R, on the right-hand-side of each slice using:

$$h_R = \frac{Z_L}{Z_R \cos\theta_R}\left[h_L \cos\theta_L - \frac{b}{2}\left(\cos\theta_L \tan\alpha + \sin\theta_L\right)\right]$$

$$+ \frac{1}{Z_R \cos\theta_R}\left[h(U_\beta \sin\beta + Q \sin\delta) - h_c k_h W \right] \qquad \textbf{(D.9)}$$

$$+ \frac{b}{2}\left[\tan\theta_R - \tan\alpha \right]$$

The General Limit Equilibrium procedure uses Eq. D.6 and D.9 iteratively to satisfy complete moment and force equilibrium for all slices. Once the factor of safety has been determined, the *total* normal, vertical and shear stresses at the base of each slice are calculated using the following equations::

$$\sigma_n = \frac{1}{b\sec\alpha}\left\{ Z_L \sin(\alpha - \theta_L) - Z_R \sin(\alpha - \theta_R)\right.$$

$$- U_\alpha + W\left[(1 - k_v)\cos\alpha - k_h \sin\alpha\right] \qquad \textbf{(D.10)}$$

$$\left. + U_\beta \cos(\alpha - \beta) + Q\cos(\alpha - \delta)\right\}$$

$$\sigma_v = \frac{W + Q\cos\delta + U_\beta \cos\beta}{b\sec\alpha} \qquad \textbf{(D.11)}$$

$$\tau_{base} = c_m + \sigma_n' \tan\varphi_m \qquad \textbf{(D.12)}$$

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Solution Procedure

The GLE solution is computed using the following steps:

1. Assume an interslice force angle distribution with θ_L for the first slice and θ_R for the last slice set to zero;
2. Determine the factor of safety, F, that allows Eq. D.6 and D.9 to satisfy force equilibrium such that Z_R for the last slice (at the crest) is equal to the boundary force. This force will be equal to the hydrostatic water force in a water-filled crack at the crest of the slope. If there is no water-filled crack, this boundary force will be zero;
3. Retain the calculated interslice forces, Z_L and Z_R that were part of the solution for the factor of safety;
4. Using the interslice forces from (3), use Eq. D.9 to calculate the magnitude of the interslice force angles, θ_R , that satisfy moment equilibrium such that h_R for the last slice is zero or equal to the location of the horizontal hydrostatic force in a water-filled crack. These calculations are performed in sequentially for each slice starting with the knowledge that θ_L and h_L for the first slice (at the toe) will be zero.
5. Repeat steps 2-5, until the calculated factors of safety and the interslice force angles are within a tolerable limit.
6. Calculate the total normal, vertical and shear stresses at the base of each slice, using Eqs. D.10 - D.12, to allow user to evaluate the reasonableness of the reported factor of safety.

D.2 Janbu's Generalized Procedure of Slices (GPS)

The GLE formulation may also be used to calculate the FOS for Janbu's Generalized Procedure for Slices (GPS). The GPS approach satisfies complete force equilibrium for all slices and moment equilibrium for all but the last slice. Force equilibrium is satisfied by implementing Eq. D.4 and D.6 for the slide-mass and moment equilibrium is satisfied for individual slices sequentially, beginning at the toe and ending at the last slice near the crest of the slope. As the location of the thrust line is assumed for this case, moment equilibrium can be satisfied by adjusting the interslice force angles.

Using Eq. D.8, derived for the GLE procedure, moment equilibrium about the center of the slice base is satisfied if:

$$Z_R \cos\theta_R \left[h_R + \frac{b}{2}\tan\alpha\right] - Z_R \frac{b}{2}\sin\theta_R$$

$$= Z_L \cos\theta_L \left[h_L - \frac{b}{2}\tan\alpha\right] + Z_L \frac{b}{2}\sin\theta_L \qquad \textbf{(D.13)}$$

$$- W k_h h_c + U_\beta h \sin\beta + Q h \sin\delta$$

In the above equation, θ_R is the only unknown if θ_L for the first slice is assumed to be zero. The interslice forces, Z_L and Z_R, calculated for force equilibrium are considered to be approximately valid. In order to solve this equation for θ_R, Eq. D.13 can be rewritten as:

$$A\sin(\psi - \theta_R) = B \qquad \textbf{(D.14)}$$

where the expansion of the above expression gives:

$$A\sin\psi\cos\theta_R - A\cos\psi\sin\theta_R = \left[h_R + \frac{b}{2}\tan\alpha\right]\cos\theta_R - \frac{b}{2}\sin\theta_R \qquad \textbf{(D.15)}$$

and

$$B = \frac{Z_L}{Z_R}\cos\theta_L \left[h_L - \frac{b}{2}\tan\alpha\right] + \frac{b}{2}\frac{Z_L}{Z_R}\sin\theta_L$$

$$- \frac{1}{Z_R}\left[W k_h h_c + U_\beta h \sin\beta + Q h \sin\delta\right] \qquad \textbf{(D.16)}$$

In seeking a solution for θ_R, the above expression may be used to determine ψ initially, and finally θ_R using the following:

$$A\sin\psi = h_R + \frac{b}{2}\tan\alpha$$

$$A\cos\psi = \frac{b}{2} \qquad \textbf{(D.17)}$$

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such that:

$$\tan\psi = \frac{2h_R}{b} + \tan\alpha$$

$$A^2 = \left(\frac{b}{2} \right)^2 + \left(h_R + \frac{b}{2} \tan\alpha \right)^2 \qquad \textbf{(D.18)}$$

and as

$$\sin(\psi - \theta_R) = \frac{B}{A} \qquad \textbf{(D.19)}$$

therefore

$$\theta_R = \psi - \sin^{-1}\left(\frac{B}{A} \right)$$

$$= \tan^{-1}\left(\frac{2h_R}{b} + \tan\alpha \right) - \sin^{-1}\left(\frac{B}{A} \right) \qquad \textbf{(D.20)}$$

This value of θ_R represents the angle that the previously calculated interslice force Z_R must maintain to satisfy moment equilibrium for the general slice. The interslice force angles calculated using Eq. D.20 lag the interslice force values calculated using Eq. D.6 by one step. However, with each new iteration for the factor of safety, force equilibrium conditions are satisfied and new interslice forces, and their lines of action, are calculated using Eq. D.20. The iterations are terminated if the difference between the old and the newly calculated factor of safety value is within a tolerable range. As the interslice force angle on the right-side of the last slice is assumed to be zero, and is not calculated using Eq. D.20, moment equilibrium is not implicitly satisfied for this one last slice. Thus although Janbu's GPS does not completely satisfy the conditions of force and moment equilibrium, it does provide the user with a solution procedure that is based on an assumed thrust line rather than a functional description of the distribution of the interslice force angles used by the GLE procedure.

Solution Procedure

The GPS approach that has been programmed into **XSTABL** is based on the following:

1. Assume a reasonable interslice force angle for all interslice boundaries;
2. Using Eq. D.6, calculate the FOS by satisfying the boundary conditions for the right-side of the last slice (same as the GLE);
3. Determine the interslice forces using Eq. D.6;
4. With the specified location of the thrust line, calculate the interslice force angles required for moment equilibrium (Eq. D.20);
5. Using the recently calculated interslice force angles, repeat steps 2-4 until the change in the FOS value is less than 0.005.

Janbu (1973) recommended that the thrust line be placed generally at about one-third of the interslice height above the failure surface. As a possible modification, it was also suggested that the thrust line may be established at slightly higher positions within the passive zone, near the toe, and slightly lower locations within the active zone near the crest of the slope. In using this method with **XSTABL**, the user can enter a normalized function to define the location of the thrust line with respect to the shear surface.

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D.3 Simplified Janbu Method

The simplified (or modified) Janbu method uses the method of slices to determine the stability of the slide mass. It is based on the forces shown, in Figure D.2, for the free-body diagram of a typical slice. *The simplified procedure assumes that there are no inter-slice shear forces* (i.e. the interslice forces are all horizontal).

Janbu's method satisfies vertical force equilibrium for each slice, as well as overall horizontal force equilibrium for the entire slide mass (i.e., all slices). Vertical force equilibrium for each slice, i, is given by:

$$\Sigma[F_v]_i = (N' + U_\alpha)\cos\alpha + S_m\sin\alpha - W(1 - k_v) - U_\beta\cos\beta - Q\cos\delta = 0 \quad \textbf{(D.21)}$$

The above equation may be arranged for N′ as

$$N' = \frac{-U_\alpha\cos\alpha - S_m\sin\alpha + W(1 - k_v) + U_\beta\cos\beta + Q\cos\delta}{\cos\alpha} \quad \textbf{(D.22)}$$

If the Factor of Safety (FOS) against shear failure is defined as **F**, and is assumed to be the same for all slices, the Mohr-Coulomb mobilized shear strength (S_m) along the base of each slice is given by:

$$S_m = \frac{C + N'\tan\varphi}{F} \quad \textbf{(D.23)}$$

where C and N′tanφ are the cohesive and frictional shear strength components of the soil. By substituting Eq. D.23 into D.22, the effective normal force acting at the base of the slice can be determined as:

$$N' = \frac{1}{m_\alpha}\left[W(1 - k_v) - \frac{C\sin\alpha}{F} - U_\alpha\cos\alpha + U_\beta\cos\beta + Q\cos\delta \right] \quad \textbf{(D.24)}$$

where

$$m_\alpha = \cos\alpha\left[1 + \frac{\tan\alpha\tan\varphi}{F}\right] \quad \textbf{(D.25)}$$

Next, the overall horizontal force equilibrium is evaluated for all slices of the slide mass.
In this case, for an individual slice i :

$$[F_H]_i = -(N' + U_\alpha)\sin\alpha - Wk_h + U_\beta\sin\beta + Q\sin\delta + S_m\cos\alpha \qquad \textbf{(D.26)}$$

then substituting for S_m from Eq. D.23 and rearranging, overall horizontal force equilibrium for the slide mass is given by:

$$\sum_{i=1}^{n} [F_H]_i = \sum_{i=1}^{n} \left[(N' + U_\alpha)\sin\alpha + Wk_h - U_\beta\sin\beta - Q\sin\delta - \frac{C + N'\tan\varphi}{F}\cos\alpha \right] = 0 \qquad \textbf{(D.27)}$$

Please note that each slice force will have a subscript i in the above equations, but has been omitted for clarity. Rearranging the above equation, the following expression may be obtained:

$$\sum_{i=1}^{n} \left[(N' + U_\alpha)\sin\alpha + Wk_h - U_\beta\sin\beta - Q\sin\delta \right] = \sum_{i=1}^{n} \left[\frac{1}{F} (C + N'\tan\varphi) \cos\alpha \right] \qquad \textbf{(D.28)}$$

Then if each slice has the same factor of safety, F,

$$F = \frac{\sum_{i=1}^{n} [C + N'\tan\varphi]\cos\alpha}{\sum_{i=1}^{n} A_1 + \sum_{i=1}^{n} N'\sin\alpha} \qquad \textbf{(D.29)}$$

where N′ is given by Eq. D.24. and

$$A_1 = U_\alpha\sin\alpha + Wk_h - U_\beta\sin\beta - Q\sin\delta \qquad \textbf{(D.30)}$$

Eq. D.29 is a ratio of the horizontal components of the available resistance and the driving forces or alternatively one can consider it as the ratio of the *available* shear strength and *driving* shear force along the failure surface. This equation is programmed into **XSTABL** for computing the uncorrected Janbu factor of safety. This format allows the state of the effective stress to be determined and appropriate corrections implemented if N′ is calculated to be less than zero. These corrections are discussed in

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section D.7 of this Appendix. **XSTABL** also computes the total available shear strength along the failure surface, $\Sigma(C + N'\tan\varphi)$, and reports this value in the summary table following a search or analysis of a single surface.

The reported Janbu FOS value is calculated by multiplying the calculated F value by a modification factor, f_o,

$$FOS_{Janbu} = f_o \cdot FOS_{calculated}$$

This modification factor is a function of the slide geometry and the strength parameters of the soil. Figure D.4 illustrates the variation of the f_o value as a function of the slope geometry (d and L) and type of soil.

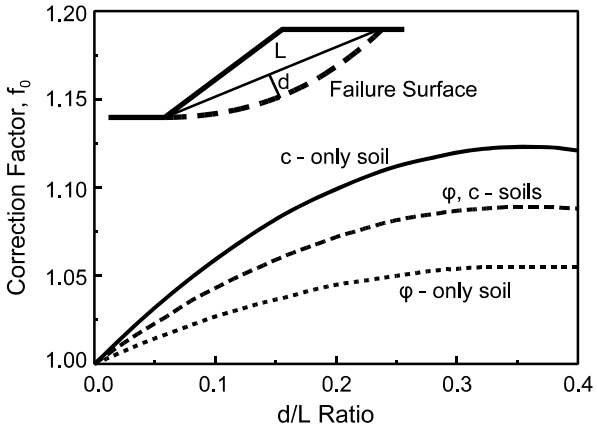

Fig. D-4. Janbu's correction factor for the simplified method

These curves were presented by Janbu in an attempt to compensate for the assumption of negligible interslice shear forces, which result in a zero interslice force angle for the simplified method. Janbu then performed calculations using his simplified and rigorous (i.e., satisfying complete equilibrium) methods for the same slopes with homogenous soil conditions. The subsequent comparison between the simplified and rigorous FOS values was used to develop the correction curves shown in Fig. D.4.

There is no consensus concerning the selection of the appropriate f_o value for a surface intersecting different soil types consisting of c-only, φ-only and c-φ soils. In cases where such a mixed variety of soils is present, the c-φ curve is generally used to correct the calculated FOS value. Within **XSTABL**, this modification factor is calculated according to the formula:

$$f_o = 1.0 + b_1 \left[\frac{d}{L} - 1.4 \left(\frac{d}{L} \right)^2 \right] \qquad \textbf{(D.31)}$$

where b_1 varies according to the soil type :

c only soils:	$b_1 = 0.69$
φ only soils:	$b_1 = 0.31$
c and φ soils:	$b_1 = 0.50$

The appropriate b_1 value is selected for use in Eq. D.30 according to the type (i.e., c only, φ only or both c and φ) of soil encountered *along* the analyzed failure surface. If a mixed soil-type is encountered, **XSTABL** uses the c and φ soil relationship described by the above expression.

D.4 Simplified Bishop Method

The simplified Bishop method also uses the method of slices to discretize the soil mass for determining the factor of safety. This method satisfies vertical force equilibrium for each slice and overall moment equilibrium about the center of the *circular* trial surface. The simplified Bishop method assumes zero inter-slice shear forces, or $\theta_L = \theta_R = 0$. Using the notation shown in Figure D.2, the overall moment equilibrium of the forces acting on each slice is:

$$\Sigma M_o = \sum_{i=1}^{n} \left[W(1 - k_v) + U_\beta \cos\beta + Q\cos\delta \right] R\sin\alpha$$

$$- \sum_{i=1}^{n} \left[U_\beta \sin\beta + Q\sin\delta \right] (R\cos\alpha - h) \qquad \textbf{(D.32)}$$

$$- \sum_{i=1}^{n} [S_m]R + \sum_{i=1}^{n} \left[k_h W(R\cos\alpha - h_{eq}) \right] = 0$$

where R is the radius of the circular failure surface, h is the average height of the slice and h_{eq} is the vertical height between center of the base slice and the centroid of the slice, as shown in Figure D.2. This equation may be simplified by dividing throughout by the radius to get:

$$\frac{\Sigma M_o}{R} = \sum_{1}^{n} [\, W\,(1-k_v) + U_\beta \cos\beta + Q\cos\delta\,] \sin\alpha$$

$$- \sum_{1}^{n} [\, S_m\,] - \sum_{1}^{n} [\, U_\beta \sin\beta + Q\sin\delta\,](\cos\alpha - h/R) \qquad \textbf{(D.33)}$$

$$+ \sum_{1}^{n} \left[k_h W \left(\cos\alpha - \frac{h_{eq}}{R}\right) \right] = 0$$

Please note that the effective normal and pore water forces, acting on the base of the slice, do not affect the moment equilibrium expression since they are directed through the center of the circle. *Thus XSTABL may not be used to compute a Factor of Safety for* ***non-circular*** *surfaces using Bishop's method!*

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If the FOS is assumed to be the same for all slices, substitute Eq. D.23 into Eq. D.32 to give:

$$F = \frac{\sum_{i=1}^{n} (C + N' \tan\varphi)}{\sum_{i=1}^{n} A_2 - \sum_{i=1}^{n} A_3 + \sum_{i=1}^{n} A_4} \qquad \textbf{(D.34)}$$

where:

$$A_2 = (W\,(1 - k_v) + U_\beta \cos\beta + Q \cos\delta) \sin\alpha$$

$$A_3 = (U_\beta \sin\beta + Q \sin\delta)\,(\cos\alpha - \frac{h}{R}) \qquad \textbf{(D.35)}$$

$$A_4 = k_h\, W(\cos\alpha - \frac{h_c}{R})$$

Next, forces are summed in the vertical direction for each slice to determine the effective normal force in the same manner as used for Janbu's method,

$$N' = \frac{1}{m_\alpha}\left[W(1 - k_v) - \frac{C \sin\alpha}{F} - U_\alpha \cos\alpha + U_\beta \cos\beta + Q\cos\delta \right] \qquad \textbf{(D.36)}$$

where m_α is given by

$$m_\alpha = \cos\alpha \left[1 + \frac{\tan\alpha \tan\varphi}{F} \right] \qquad \textbf{(D.37)}$$

Eqs. D.34 - D.37 are the expressions that are programmed into **XSTABL**, to calculate the factor of safety for circular surfaces according to the simplified Bishop Method.

D.5 Reinforced Slope Analysis

XSTABL may be used for the analysis and design of steep soil-slopes that are to be reinforced with geogrids or geotextiles. The approach is based on the Coulomb analysis used for the assessment of lateral earth forces for design of frictionless retaining walls. The proposed methodology uses **XSTABL** to analyze the soil slope for the following three conditions :

1. Identification, via a search, of a potential failure surface that requires the greatest external force to maintain stability at a specified, post-construction FOS,

2. Minimum FOS for a critical surface in the unreinforced soil-slope,

3. Delineation of a reinforced zone to satisfy requirements of external stability.

Once the above analyses have been performed, the engineer can then select an appropriate reinforcing system that can provide the required external resistance reported by analysis performed according to item 1, above. The design is completed by ensuring that the reinforcement is adequately embedded beyond the reinforced zone (item 3, above).

If a minimum Factor of Safety (FOS), F_{min}, is specified by the user, the external force required to maintain a specified FOS may be calculated using Eqs. D.29 (Janbu) and D.34 (Bishop). The effective normal force, N′, is calculated for both the Bishop and Janbu methods using Eq. D.24 or D.36 with the specified FOS value:

$$N' = \frac{1}{m_\alpha}\left[W(1 - k_v) - \frac{C \sin\alpha}{F_{min}} - U_\alpha \cos\alpha + U_\beta \cos\beta + Q\cos\delta\right] \qquad \textbf{(D.38)}$$

where

$$m_\alpha = \cos\alpha\left[1 + \frac{\tan\alpha\tan\varphi}{F_{min}}\right] \qquad \textbf{(D.39)}$$

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Once the effective normal force is calculated, the new FOS value, $F_{calculated}$, is computed using either Eqs. D.29 or D.34 for Janbu's or Bishop's FOS. Typically $F_{calculated}$ will be less than F_{min} if the slope requires reinforcement. Then the magnitude of the external *horizontal* resisting force or moment, **ΔF** and **ΔM**, required to maintain stability with a FOS of F_{min} may be calculated using one of the following:

For Janbu's Method:

$$\Delta F = (F_{min} - F_{calculated}) \left[\sum_{i=1}^{n} A_1 + \sum_{i=1}^{n} N' \sin\alpha \right] \quad \textbf{(D.40)}$$

and for Bishop's Method:

$$\Delta M = (F_{min} - F_{calculated})\, R \left[\sum_{i=1}^{n} A_2 - \sum_{i=1}^{n} A_3 + \sum_{i=1}^{n} A_4 \right] \quad \textbf{(D.41)}$$

where A_1, A_2, A_3 and A_4 are the same as defined earlier and R is the radius of the circular failure surface. If Bishop's method is used, the magnitude of the external reinforcing force may be determined for a specified elevational location of this resultant force. The analysis assumes that the reinforcing force is horizontal for both methods.

Then if the moment arm of the reinforcement force is $y_{\Delta F}$, the force will be given by:

$$\Delta F = \frac{\Delta M}{y_{\Delta F}} \quad \textbf{(D.42)}$$

In **XSTABL**, the user must specify the elevation of the resultant force that simulates the expected reinforcement stress distribution. This elevation is compared to the y-coordinate of the center of the circular surface to find the moment arm, $y_{\Delta F}$.

In order to assess the external stability of the reinforced slope, a reinforced zone is included in the analysis. This zone is specified as consisting of "new" soil units with the strength, φ_{reinf} and c_{reinf}, increased to simulate the effects of the reinforcement. The increase in the shear strength parameters is based on the analysis of the unreinforced slope.

If the critical FOS value for the unreinforced slope is given by F_{crit}, and the required FOS for the reinforced slope is F_{min}, then the soil strength parameters are modified according to:

$$\varphi_{reinf} = \tan^{-1}\left[\frac{F_{min}}{F_{crit}} \tan\varphi_{orig}\right] \quad \textbf{(D.43)}$$

$$c_{reinf} = \frac{F_{min}}{F_{crit}} \left[c_{orig} \right] \quad \textbf{(D.44)}$$

The user may then manipulate the size of this reinforced zone in order to satisfy the requirements for external stability.

As an initial guidance, the reinforced zone should be selected such that it is at least 3 feet (or one meter) beyond the critical surface identified during the search for the external force, as shown in Fig. D.5. Once the extent of the required reinforced zone is identified, the user should ensure that the proposed reinforcement extends beyond these boundaries and has adequate pull-out resistance (i.e., embedment).

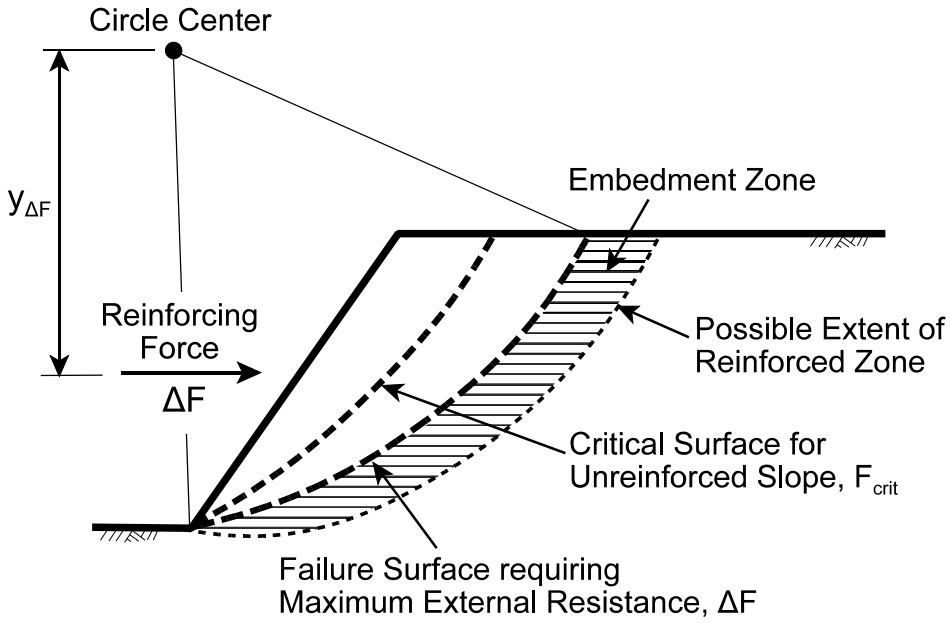

Fig. D-5. Location of critical surfaces for reinforced and unreinforced slope

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D.6 Nonlinear Mohr-Coulomb Analysis

Most slope stability analyses use a Mohr-Coulomb failure envelope that is linear for ***all*** effective stress ranges. This linearity is simulated by constant shear strength parameters: c' and φ'. However, in cases where the strength of the soil, ***in the slope***, is strongly dependent on the normal effective stress, **XSTABL** allows the user to implement a non-linear (or curved) Mohr-Coulomb shear strength envelope. The input data for this option is based on laboratory, or field, test data presented on a conventional σ - τ plot, and consists of simulating the curved envelope with a series of discrete (σ, τ) points. These data points are transformed internally to represent a series of "straight" line Mohr-Coulomb envelopes, each with a constant c' and φ' over a particular stress range.

The factor of safety computations follow the same order as outlined earlier, but the c' and φ' parameters are selected according to the calculated normal effective stresses acting at the base of each slice. This process is repeated until compatibility is achieved between the calculated normal effective stresses and the selected soil strength parameters. Depending on the curved envelope data, these calculations usually require 2 or 3 additional iterations in comparison to calculations based on a linear Mohr-Coulomb envelope.

D.7 Control of Negative Effective Stresses

The limit equilibrium method that has been implemented can sometimes lead to numerical difficulties that are manifested by **negative** normal effective stresses calculated along the failure surface. A detailed study of negative normal effective stresses can only be made for cases where a single surface is being analyzed and the user can review the extensive slice data written to the output file. However, for cases where a search for the most critical surface is being performed, it is difficult to review the reported results for each potential failure surface and thus the user will have to decide on an appropriate plan of action if negative stresses are encountered during the analysis. Hence, the ensuing discussion concerning the control of negative normal stresses is directed towards such search analyses that use the simplified Bishop and Janbu methods of analysis.

The normal effective stress for the simplified Bishop and Janbu methods can be calculated using:

$$\sigma' = \frac{N'}{b\sec\alpha}$$
$$= \frac{\cos\alpha}{b m_\alpha}\left[W(1 - k_v) - \frac{C \sin\alpha}{F} - U_\alpha\cos\alpha + U_\beta\cos\beta + Q\cos\delta \right] \quad \textbf{(D.45)}$$

where

$$m_\alpha = \cos\alpha\left[1 + \frac{\tan\alpha\tan\varphi}{F} \right] \quad \textbf{(D.46)}$$

Negative effective stresses are usually encountered in Eq. D.45 for cases that involve:

(1) ***high*** pore water pressures,

(2) a combination of thin slices with a low self-weight and a high "c-value",

(3) ***steep*** slice-base angles.

Most of these problems are associated with the indeterminacy of the limit equilibrium analysis and the failure to adequately satisfy the conditions for complete static equilibrium.

The influence of negative effective stresses for a slice within the *last five percent of the total number of slices* near the crest of the failure surface being analyzed are neglected by **XSTABL**. This criteria has been established on the basis that the upper portion of a failure mass may pass through a potentially *cracked* zone. For such cases, **XSTABL** "ignores" the strength contribution of these last few slices (i.e., sets shear strength to zero), if calculations reveal a negative normal effective stress. An error is ***not*** reported for such cases.

If a ***negative*** effective normal stress is calculated and the slice is not within the last five percent of the total number of slices, **XSTABL** examines the scenario and attempts to correct the problem if the negative stresses are due to excessively high pore water pressures. In such cases, the *total* normal stress is computed by adding the pore water pressure to the calculated effective stress. If this results in a positive total stress, it is concluded that the pore water pressures are excessive and the effective stress is set to ***zero***. This control essentially "reduces" the calculated pore water pressure at the base of the slice, thus eliminating the negative effective stress that had been computed initially. If such a correction is made for any potential failure surface during the analysis, an explanatory warning message is written to the output file.

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If control of excessive pore water pressures fails to eliminate the computed negative effective stress, **XSTABL** concludes that the combination of a small W and a relatively large C component in Eq. D.44. is the problem. In this case the user is cautioned on-screen and asked to select one of the following three options:

Option-1: Proceed with analysis, but enforce the condition that the Mohr-Coulomb shear strength, $\tau = c' + \sigma' \tan\varphi$, is ***always*** greater than or equal to zero.

Option-2: Proceed with analysis without any restrictive conditions concerning the computed shear strength;

Option-3: Proceed with the analysis, but only retain and summarize the factor of safety values for surfaces that did not have any calculated negative effective stress values (i.e., within the initial 95 percent of slices). *However, the parameters of the erroneous surface (and its FOS based on unrestricted S_m values) are written to the **XSTABL** output file for information.*

The selected option remains in effect for the current analysis only. For subsequent analyses, the user will be prompted to make a "fresh" selection. An error message, ERROR #48, is written to the output file followed by an explanatory message indicating the option that was selected for the subsequent analysis.

In selecting option (1), the assumption that all slices have the same FOS such that the shear strength, S_m, given by

$$S_m = \frac{C + N' \tan\varphi}{F} \geq 0 \qquad \textbf{(D.47)}$$

will be violated if S_m is arbitrarily adjusted to ensure that it is not less than zero. This restriction implies that for the cases where S_m would have been less than zero, the FOS for the slice is implicitly increased to infinity to ensure zero shear strength. This assumption implicitly contradicts the FOS value used in Eq. D.23 to calculate N' that is subsequently used in Eq. D.24. Although this is offered as the default option for practical convenience, it is important that users recognize the implication of these assumptions. The alternative option (2) does not violate the limit equilibrium assumption of a constant FOS for all slices. Thus it will always generate the lowest factors of safety as the strength mobilized along the failure surface will be a minimum because S_m may be calculated to be less than zero for some slices.

Please note that the FOS values resulting from the selection of options (1) or (2) will be identical if values of $S_m < 0$ are not computed during the analysis. For other cases where $S_m < 0$ is computed, the FOS values will be different depending on whether the user selects option (1) or (2). In certain circumstances where unusual geometric conditions exist, significantly different FOS values may be reported by **XSTABL**. Interestingly, it is also possible that if the φ-angle for the offending layer is increased, the FOS may be ***reduced*** due to the mobilization of *negative* frictional strength. Two examples illustrating this problem are presented at the end of Chapter 5.

Finally, ERROR # 50 is written to the output file if negative stresses are computed for the rare cases that m_α, calculated using Eqs. D.25 or D.37 or D.46, becomes negative. This informs the user that the negative normal effective stresses were computed due to steep negative angles at the base of the slices near the toe of the slope.

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APPENDIX E

SEARCHING TECHNIQUES

XSTABL implements the three trial surface generators programmed into STABL4 with some modifications that improve their overall reliability. These automatic generators can provide: (1) circular, (2) noncircular, or (3) block shaped surfaces for analysis. These greatly facilitate the slope analysis process by automatically generating surfaces that may be subsequently examined with respect to their factor of safety. This is a necessary procedure as a closed form solution for a critical surface with a minimum factor of safety is not available for heterogenous slopes. Once a satisfactory number of surfaces have been examined, the surface with the lowest factor of safety is generally pronounced to be the critical failure surface.

E.1 Random Numbers

All three trial surface generators use a series of pseudo random numbers to develop different surfaces for the stability analysis. These random numbers are generated, in **XSTABL**, using a FORTRAN function presented by Press et al. (1986). This function generates a sequence of real numbers with magnitudes that are uniformly distributed between 0 and 1. The algorithm has been successfully tested to ensure that the random number sequence is not repeated within the first 100,000 calls to the programmed function.

A modification of the original algorithms allows the function to be initialized at the beginning of each analysis. Thus during an **XSTABL** analysis, the same sequence of random numbers will be accessed in ***every instance***, allowing the user to duplicate previous results. However, this does limit the truly "random" generation of surfaces. This is manifested during the analysis by the inability of **XSTABL** to generate additional "new" surfaces without changing the input data.

This would occur, for example, when the user generates and analyzes 200 surfaces, and then follows the same analysis by requesting the analysis of another 100 (say) trial surfaces. However in this case, the first 100 surfaces that were generated in the previous analysis of 200 surfaces would be generated again, leading to a redundant analysis. In such cases, it is recommended that the user change one of the surface generation parameters (e.g. segment length or the initiation / termination limits). With such a change, additional *new* trial surfaces can be generated successfully to supplement a previous analysis.

Within **XSTABL**, the STABL4 methodology is used to effectively generate the segments that form the trial failure surface. The rules and conditions that control the use of the random numbers for the different surface generators is described below.

E.2 Circular Surface Generation

Circular surfaces are generated by using two random numbers only. The first number defines the orientation of the initial (first) segment of the failure surface and the second random number is used to establish the orientation of the remaining segments of the circular surface.

The first random number is used to determine the angle of the initial segment of the failure surface, within user defined upper and lower angular limits, as it is generated in a left to right direction (see Fig. E.1).

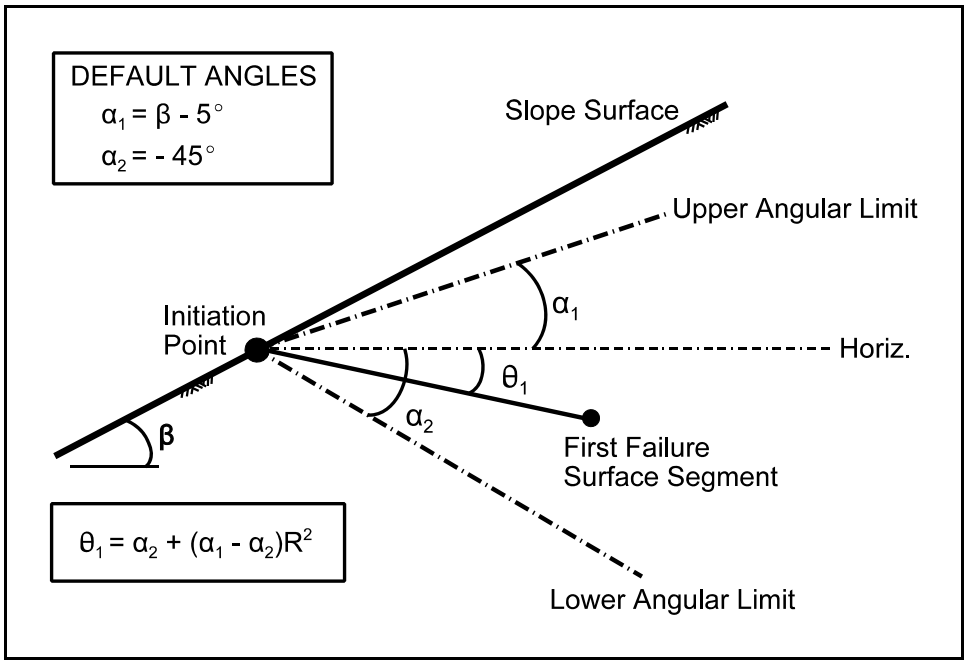

Fig. E-1. Selection of initial line segment for circular surface generation *(angles are measured positive CCW from the horizontal)*

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Also, a bias in selecting this angle is introduced by using the square of the random number:

$$\theta_1 = \alpha_2 + (\alpha_1 - \alpha_2)\, R^2 \qquad \textbf{(E.1)}$$

where R is the random number and the angles are as defined in Fig. E.1.

The probability of the location of the initial failure surface segment within an upper and lower angular limit range that has been subdivided into ten equal sectors is illustrated in Fig. E.2. From this figure, one can see that the introduced bias results in the initial segment being located within the sector closest to the lower angular limit for about 32 percent of the cases. The probability for a segment close to the upper angular limit is only about 5 percent.

This bias leads to initial segments that are nearer to the lower angular limit and is introduced primarily to obtain trial surfaces that are deeper. During the development of the STABL program, it was found that a poor distribution of the factor of safety values was obtained if the initial segment was given an equal likelihood of being oriented in any direction within the specified angular directional limits.

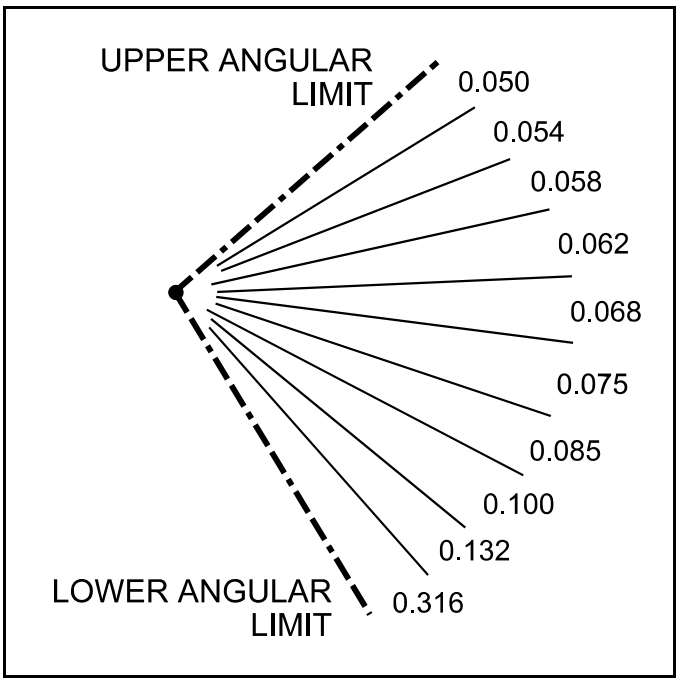

Fig. E-2. Probability of orientation of initial line segment for circular and noncircular surfaces generation

Once an initial segment is selected, the remaining portion of the proposed circular surface is generated such that it intersects the ground surface within the specified termination range. These circles will all start from the initiation point (near the toe in Fig E.3), have a common first segment and be confined within the region shown in Fig. E.3. All such surfaces are generated so that the termination point is always *above* the elevation of the initiation point.

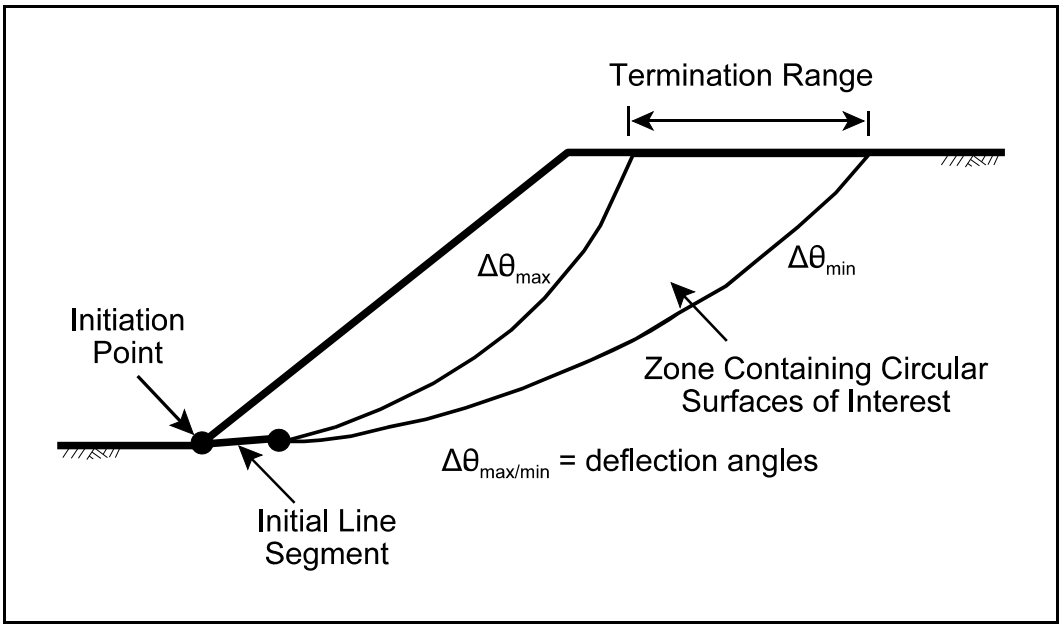

Fig. E-3. Calculation of deflection angles for circular surface generation

The segments that compose a circular shape have fixed lengths, T, and each successive segment is deflected by a constant angle, $\Delta\theta$, with respect to the preceding segment as shown in Fig. E.4. The deflection angle may be calculated according to :

$$\Delta\theta = 2 \sin^{-1}\left[\frac{T}{2r}\right] \qquad \textbf{(E.2)}$$

where r is the radius of the circle. The STABL4 algorithms determine this deflection angle, $\Delta\theta$, required to encompass the potential range of the termination limits. In Fig. E.3 the two angles $\Delta\theta_{max}$ and $\Delta\theta_{min}$ correspond to circular surfaces terminating at the left and right termination range, respectively. Effectively, the $\Delta\theta_{max}$ and $\Delta\theta_{min}$ range corresponds to the shaded area shown in Fig. E.3 and allows for a random selection of the remaining segments of a circular surface.

The fixed deflection angle, $\Delta\theta$, for the remaining segments is selected within this $\Delta\theta_{max}$ and $\Delta\theta_{min}$ range by using the expression :

$$\Delta\theta = (\Delta\theta_{max} - \Delta\theta_{min})\, R^2 \qquad \textbf{(E.3)}$$

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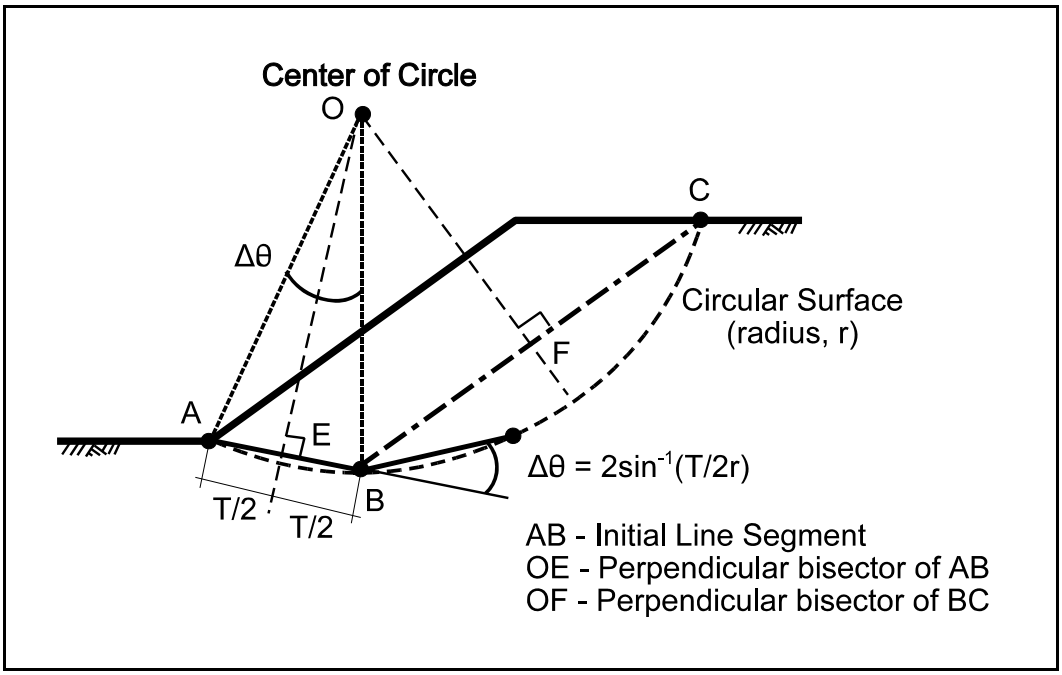

Fig. E-4. Calculation of deflection angles for circular surface generation

The orientation of each successive segment will then be given by the inclination of the previous segment plus the randomly generated deflection angle,

$$\theta_i = \theta_{i-1} + \Delta\theta \qquad \textbf{(E.4)}$$

The above approach of selecting the orientation of the first segment followed by a deflection angle forms the basis of the circular surface generator in STABL4 and **XSTABL**. However, there are cases where small adjustments have to be made to accommodate the slope geometry and user defined limitation. Such examples are discussed below.

Adjustment of Δθ:

1. If Δθ is calculated such that it is less than zero (suggesting a convex surface), it is changed to a minimum limiting deflection angle of 0.0. This corresponds to a planar surface that intersects the ground within the specified termination limits.
2. If $\Delta\theta_{max}$ is less than zero, only convex surfaces may be generated from the initial segment (see Fig. E.5). In such cases, the upper angular limit is reduced to θ_1, the orientation of the currently selected initial segment, and the search is restarted with a new initial segment to seek a desirable, concave circular surface. This step is repeated until a positive $\Delta\theta_{max}$ value is obtained for the maximum deflection angle.

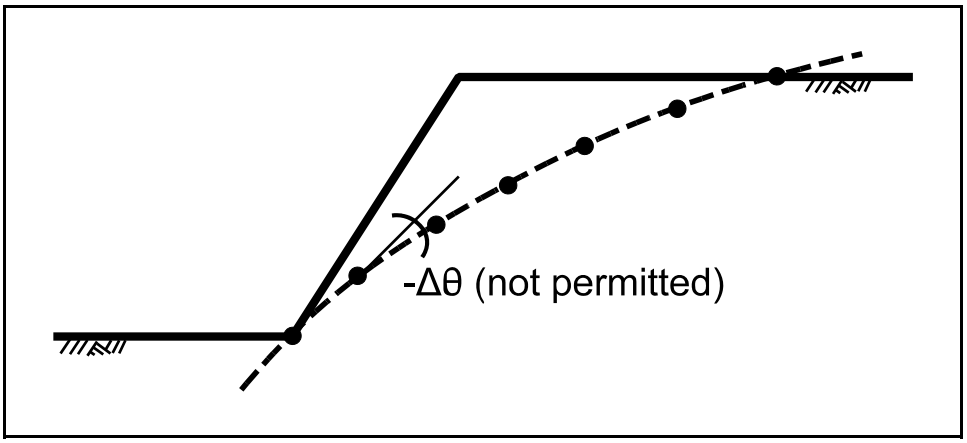

Fig. E-5. Unsuitable convex failure surface generated by a negative deflection angle

3. $\Delta\theta_{max}$ is limited to an angle less than 45° as larger deflection angles will lead to a poor approximation of a circular surface (see Fig. E.6).

4. If $\Delta\theta_{min}$ greater than 45°, the lower angular limit is changed to θ_1, similar to case 2 above, and the search is repeated with a new initial segment for an acceptable $\Delta\theta_{min}$ value.

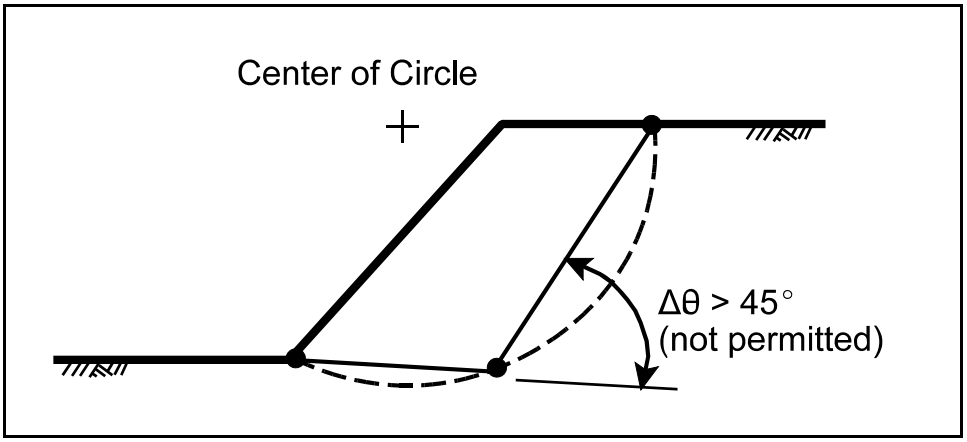

Fig. E-6. Maximum limit for deflection angle for generation of suitable circular surfaces

5. An overturned shear surface may be generated if the center of the circle is below the elevation of the termination range, as shown in Figure E.7. This problem is avoided by reducing $\Delta\theta_{max}$ such that a circle center corresponding to the left termination limit is at least T/2 above the elevation of the termination range (Fig. E.8). The overall effect of this feature is to move the left termination limit to the right.

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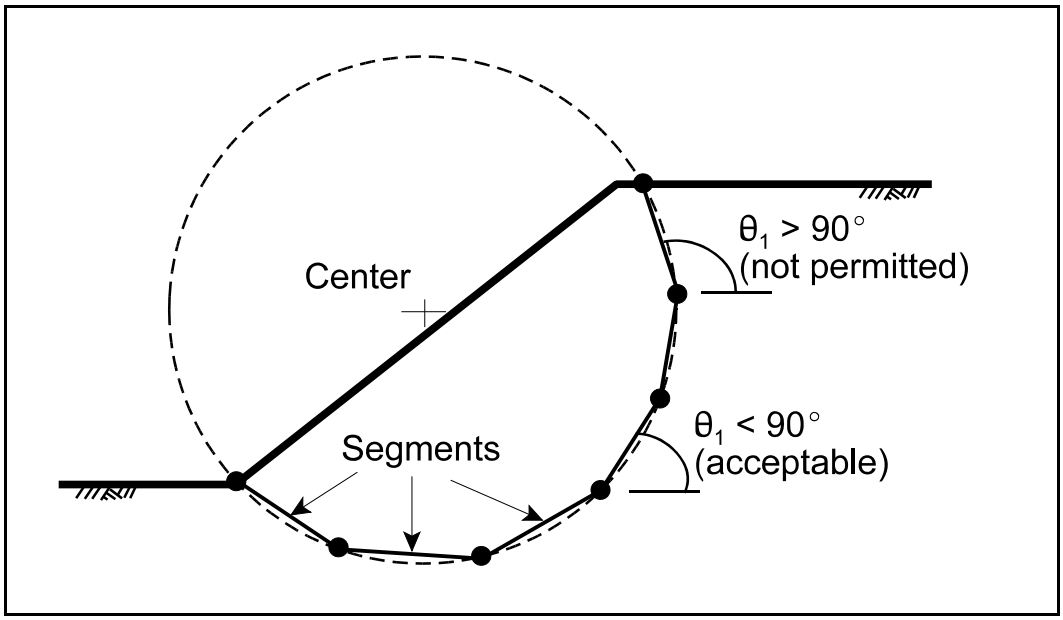

Fig. E-7. Unsuitable, reversed surface with upper line segment orientations exceeding 90°

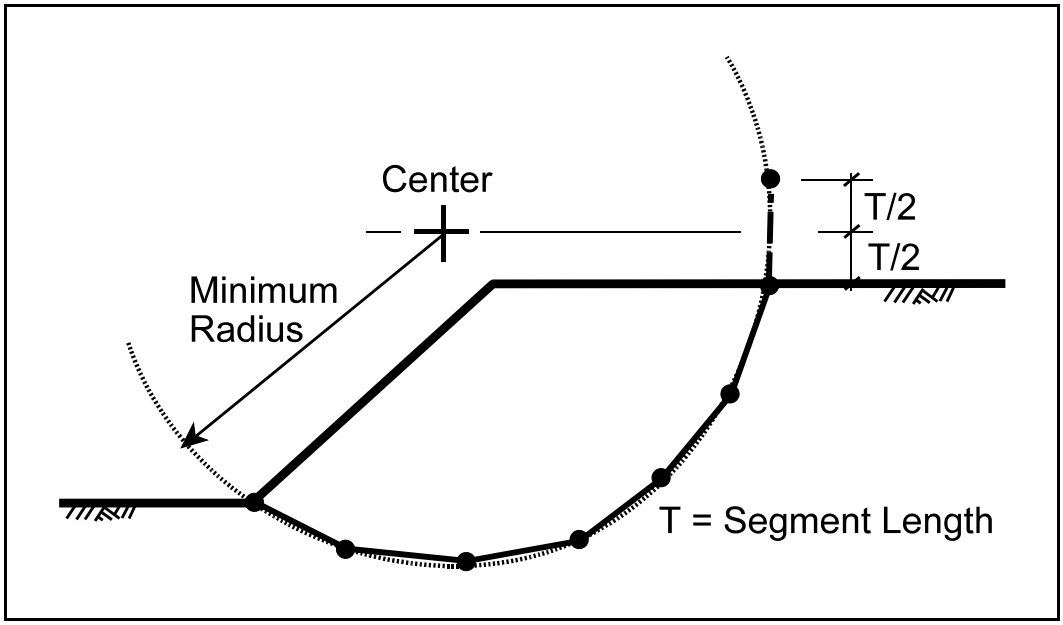

Fig. E-8. Limitation imposed on elevation of circle center for generating suitable surfaces

6. If overturned surfaces may be generated for segments passing through the right termination limit the lower angular limit is changed to the current initial segment orientation, θ_1, and the search process repeated with a new initial segment.

7. If the assigned lower angular limit, α_2, prevents a successful generation of the initial segment (Fig. E.9), the value of α_2 will be adjusted to allow generation, accordingly.

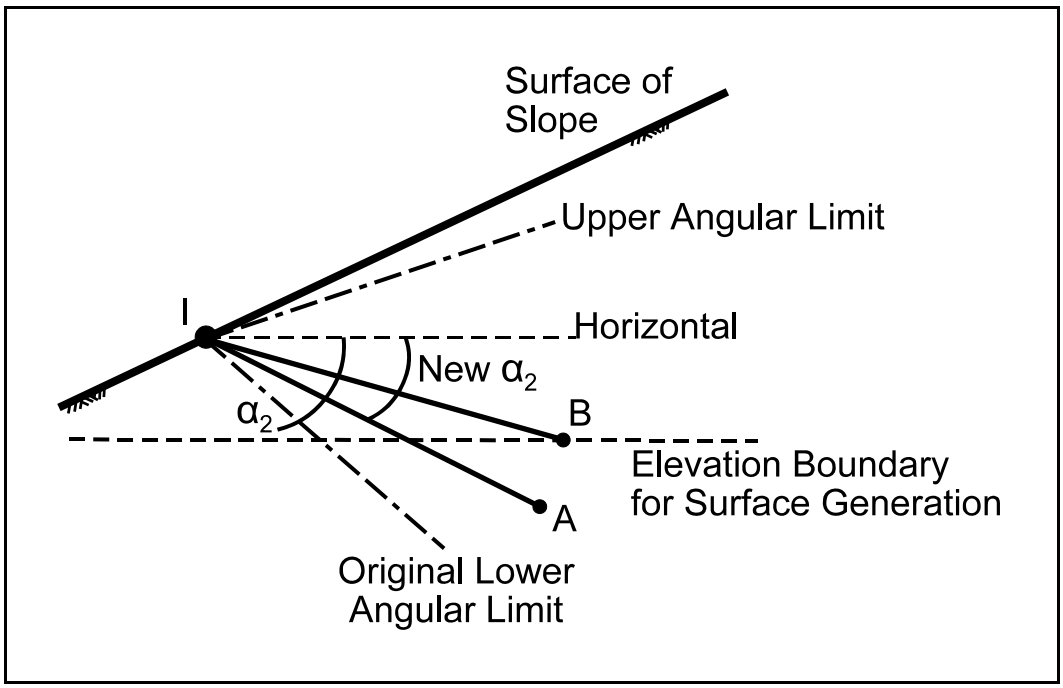

Fig. E-9. Adjustment of lower angular limit if an elevational boundary prevents successful generation of the initial line segment

8. If a segment impinges into a user defined boundary, $\Delta\theta_{min}$ is adjusted to allow space for surface development. However, if this results in $\Delta\theta_{min} \geq \Delta\theta_{max}$, the lower angular limit, α_2, is adjusted until a satisfactory surface is generated.

9. If segments intersect a lower boundary, the algorithms check to ensure that a surface can indeed be successfully generated by using $\Delta\theta_{max}$ as the deflection angle from the initial segment. If a surface is possible, the search process is continued with a new initial line segment. However, if a surface cannot be generated with $\Delta\theta_{max}$, $\Delta\theta_{min}$ is changed to the deflection angle, $\Delta\theta$, of the surface that originally intersected the boundary. The process is then continued with the selection of a new deflection angle within the newly defined $\Delta\theta_{min}$ - $\Delta\theta_{max}$ range. This has the same effect as moving the right termination limit to the left.

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10. For intersection with upper boundaries, the adjustment is similar except that the $\Delta\theta_{min}$ value is used to determine if any surfaces can be successfully generated. If an intersection does occur, the $\Delta\theta_{max}$ value is adjusted to $\Delta\theta$ in an attempt to continue generating desirable surfaces.

E.3 Irregular Surface Generation

The initial segment of an irregular surface is generated in the same manner as that employed for the circular surface. The remaining trial surface segments are generated sequentially, from left to right, using randomly generated deflection angles.

A narrow angular range is randomly determined and then a deflection angle is calculated within this range to generate the next trial surface segment. This angular range extends 45° CCW and 18 R^2 ° CW from a line produced as an extension of the previously generated trial surface segment. This is illustrated in Fig. E.10, which shows the generation of a new segment **AB** from the end of the initial segment **IA**.

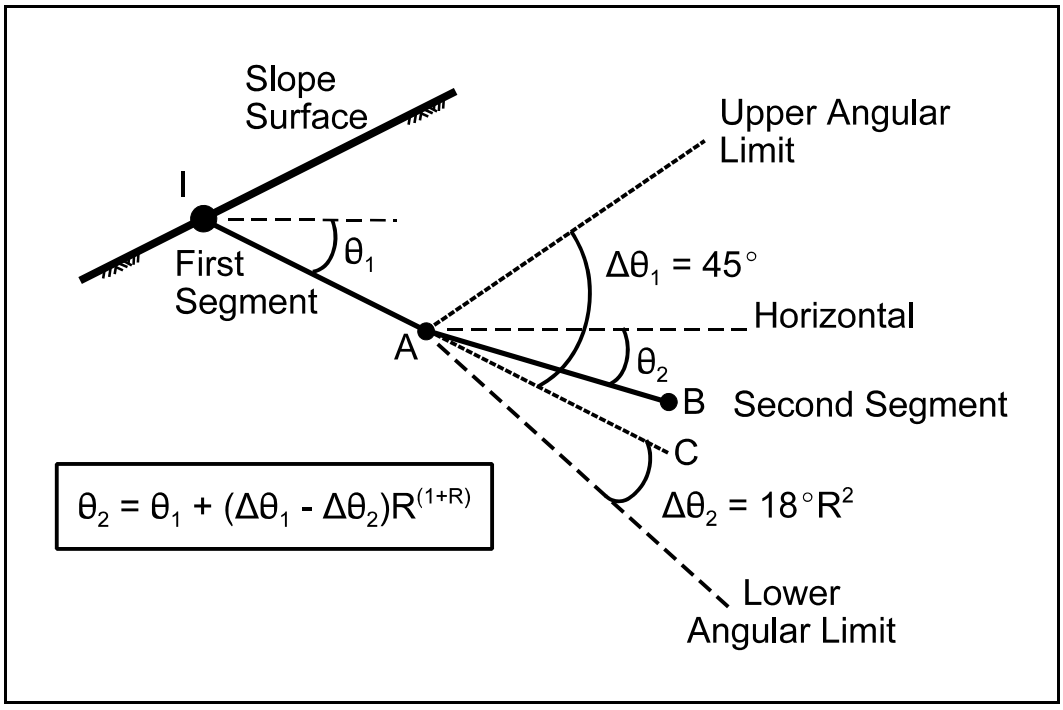

Fig. E-10. Orientation of line segments for irregular surface after generation of initial line segment

An adjustment to the CCW angular range, $\Delta\theta_1$, is made if the inclination of the previous trial surface segment is greater than 45°. This effectively prevents the possible generation of a vertical segment by limiting the CCW range.

A random number is then used to select the orientation angle, θ, within this angular range according to:

$$\theta = \theta_2 + (\Delta\theta_1 - \Delta\theta_2)\, R^{(1+R)} \qquad \textbf{(E.5)}$$

This tends to favor angles that are closer to the inclination of the previous trial surface segment. The allowable CCW angular range ($\Delta\theta_1$) is 45° compared to the 0° to 18° CW range ($\Delta\theta_2$), as measured from a projection of the previous segment. Thus there is a greater probability that a majority of positive deflection angles will be generated by the algorithm. These positive angles will generate a desirable surface that is predominantly concave with a few convex "kinks".

The irregular surface generator is more computer intensive than the circular or block surface generators as there is no prior knowledge regarding whether the surface will :

(a) intersect the ground surface within the specified termination limits, or

(b) intersect an upper or lower boundary, or

(c) intersect a lower elevational boundary.

If any of the above conditions is violated, the current surface being generated is discarded for most cases and a search for a another viable surface is started with a new initial segment. Hopefully, the next sequence of random numbers will then permit a surface to be generated successfully.

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Minor adjustments, similar to the circular surface generator, are also made for the irregular surfaces.

(a) If a segment extends beyond the right termination limit or intersects the specified minimum elevation (i.e. a boundary), the possibility of successfully bypassing the boundary is checked by using a deflection angle equal to $\Delta\theta_1$. If the boundary can be bypassed, the CW limit is adjusted to 0° and a new deflection angle is selected within the CCW angular range. However, if the segment still intersect the boundary, it is rejected and a new search started.

(b) If a segment intersects an upper or lower boundary, procedures similar to those listed above are used to adjust the CCW or CW angular ranges, accordingly.

In order to reduce the number of segments needed to complete a failure surface, the user should try to use large segment lengths, preferably in the range H/4 to H/3, where H is the maximum elevational difference between the initiation and termination ranges. With such lengths, the chances of generating unsuitable surfaces are reduced considerably.

Users should note that the **XSTABL** algorithms generate a smoother transition than the original STABL program by limiting the clockwise angular range to a maximum of 18° rather than the 45° used in STABL4. This effectively eliminates the overly "kinky", reversed surfaces that were generated with larger negative deflection angles.

E.4 Block Surface Generation

XSTABL offers the same two methods for generating block shaped surfaces as used in STABL4. This option is recommended for cases where the user wishes to generate trial surfaces that closely follow a relatively "weak" layer. This option is also suitable for analyzing translational slope failures which often tend to follow the soil-rock interface.

The block surfaces are developed by connecting points that have been randomly selected within user specified **search boxes** as shown in Fig. E.11. The generated block surfaces consist of three distinct portions: (1) passive block, (2) central block and (3) active block, as shown in Fig. E.11.

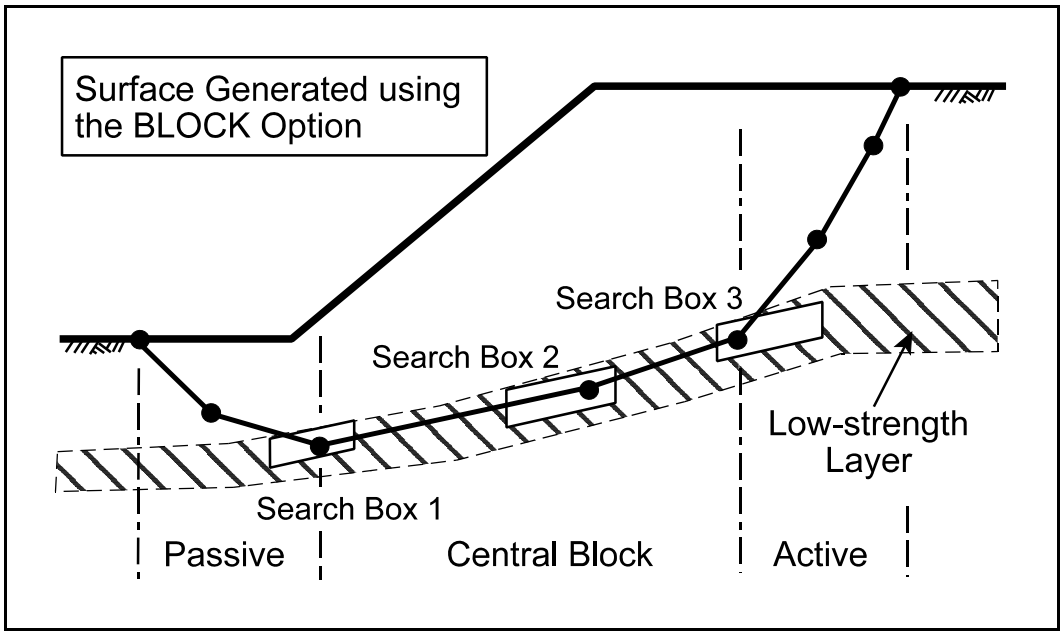

Fig. E-11. Generation of block-shaped surfaces through a low-strength soil layer using three search boxes

For both the **Rankine** and **Block** options, the central block is generated by:

1. Randomly selecting an x-coordinate within the horizontally defined boundaries of the search box as:

$$x = x_{left} + R_1 \left[x_{right} - x_{left} \right] \qquad \textbf{(E.6)}$$

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2. Randomly selecting a y-coordinate within the specified boundaries of the search box according to:

$$y = y_{left} + R_1 \left[y_{right} - y_{left} \right] + H \left[R_2 - 0.5 \right] \quad \textbf{(E.7)}$$

where R_1 and R_2 are random numbers and H is the height of the search box.

Although the central block for these surfaces are the same for the two options, the active and passive wedges are generated differently. The central block is generated first and is then followed by generation of the passive and active wedges. The passive wedge is generated from the leftmost search box and the active wedge extends upwards from the righmost search box.

Rankine Wedges

These are generated according to the assumption that the limiting surface will be a function of the angle of internal friction (φ) of the soil. Thus for the passive wedge, the failure surface segments will be inclined at (45 + ½φ) degrees, CCW from the vertical, as shown in Figure E.12. Similarly, the failure surface segments for the active wedge will be inclined at an angle of (45 – ½φ) degrees, CW from the vertical. In slopes with multiple soil layers, the inclination of the failure surface segments for the passive and active wedges will vary according to the φ-values of each soil unit. *For cases where the Rankine passive or active failure surface passes through a soil layer that is defined by either anisotropic or curved Mohr–Coulomb strength parameters, the φ-value is selected from the value defined for the isotropic properties.*

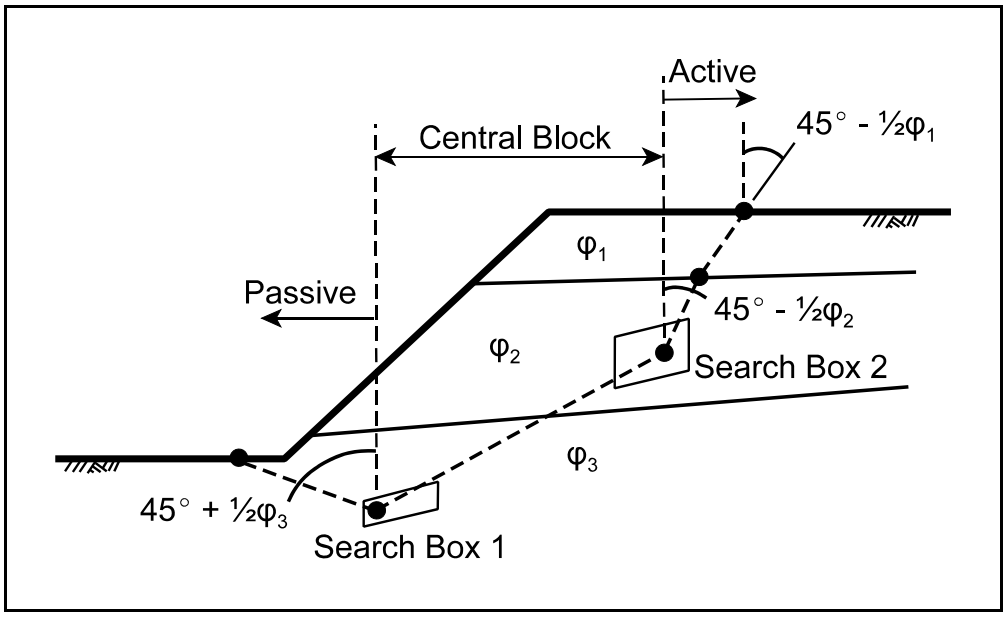

Fig. E-12. Rules used to generate the active and passive line segments for the RANKINE option

Block Wedges

This option develops the passive and active wedges of the failure surface (see Figure E.13) using an approach that is similar to the generation of irregular surfaces. The passive portion is generated by randomly selecting a segment inclination that ranges between 0° and −45°, measured CCW from the horizontal according to the equation shown below:

$$\theta = (-45 + 45R^2)° \quad \textbf{(E.8)}$$

The active portion of the block surface is similarly generated using :

$$\theta = (45 + 45R^2)° \quad \textbf{(E.9)}$$

The user must exercise care in selecting the segment length for the **Block** option as small value may result in the generation of an admissible surface.

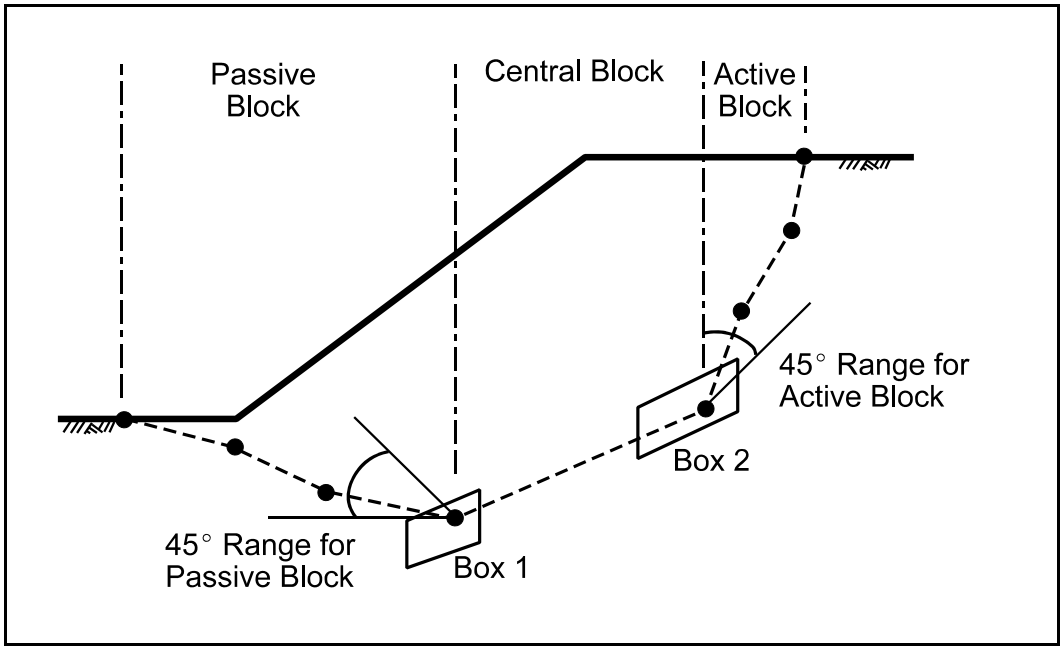

Fig. E-13. Rules used to generate the active and passive line segments for the BLOCK option

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Search Boxes

The dimensions of the search boxes may be manipulated to control the location of the search area through which **XSTABL** will generate potential failure surfaces. At first glance, it appears that the user is asked to specify trapezoidal shaped search boxes. However, the dimensions of these boxes can be specified to simulate a line or a point through which all generated surfaces must pass.

"**Line Boxes**": Figure E.14 shows a search box which reduces to a line as the side length has been specified as zero. The use of this method is very effective for cases where the failure surface is expected to follow a "thin", low strength soil layer or a soil-rock interface. Appropriate use of the side length and the left and right side coordinates allow the user to generate a "line-box" of any length and orientation.

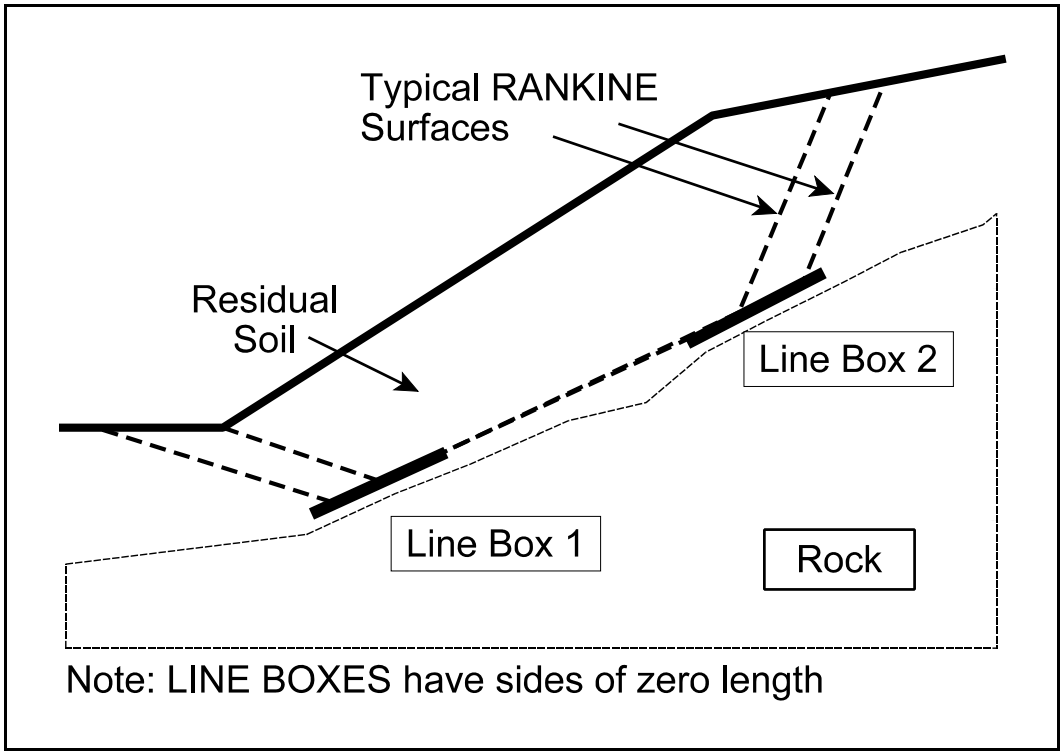

Fig. E-14. Suggested use of a "LINE" box that is simulated with a side height of zero

"**Point Boxes**": Figure E.15 shows a case where the coordinates of the left and right middle points of the specified search boxes are the same, and the side length has also been specified as zero. With these dimensions, the trapezium reduces to a point. This powerful technique forces all generated failure surfaces to pass through a point. In the example illustrated in Figure E.15, "point-boxes" located near the surface boundary at two locations effectively force all failure surfaces to start and end at the same locations on the slope.

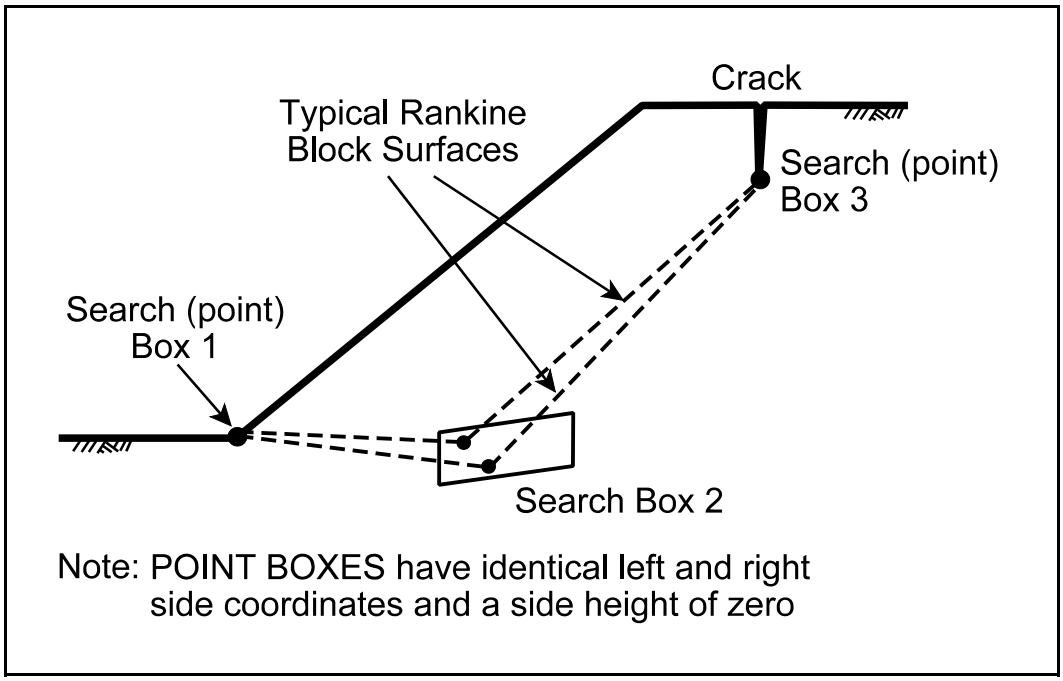

Fig. E-15. Suggested use of a "POINT" box, with side height of zero and identical (x, y) coordinates for the left and right sides, for controlling exit point of block-shaped surfaces

NOTE

Please note that if a lower limiting boundary is specified along with search boxes for the Rankine-block analysis, the limiting boundary is neglected by **XSTABL**. Thus if search boxes have been established so that they overlap a lower limiting boundary, the user cannot expect **XSTABL** to implicitly only generate surfaces that do not penetrate this limiting boundary. If a limiting boundary, along with search boxes for a Rankine-block search, is specified, an explanatory warning message will be written to the output file.

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APPENDIX F

DETERMINATION OF SLICE DATA

Once a potential failure surface has been generated, or specified by the user, the method of slices may be used to determine the factor of safety. In this chapter, the various parameters that define the slices are discussed along with the approach used to discretize the slope mass into slices.

F.1 Determination of Slice Widths

The slide mass is divided into slices with vertical sides according to the specified slope geometry and the potential failure surface. The location of vertical sides will occur at:

1. each specified x-coordinate used to define the surface and subsurface boundaries located directly above the failure surface under analysis,
2. each x-coordinate of the specified water surfaces that are likely to affect the slide mass,
3. each intersection of a water surface and subsurface boundary,
4. each intersection of the failure surface segments with a subsurface boundary or water surface,
5. each lateral boundary used to define a surface surcharge load.

The above criteria will result in slices that have straight sides, and may include several soil types and the effects of different water surfaces. All these specific effects will be simulated by boundaries that are straight lines between the left and right hand sides of each slice.

Thus if a user wishes to have many slices generated (within an overall maximum of 100 slices), a small failure segment length and many slope geometry coordinates will result in the use of a large number of slices. However, this will also directly affect the time required for performing the computations. On the basis of the author's experience, a slide mass discretized into more than twelve slices is likely to lead to reliable results for most soil conditions.

F.2 Calculation of Slice Weight

The program determines the soil types that are contained within any slice mass and determines the total weight according to the specified unit weights. These weights are selected according to the following:

1. Soil Unit completely *above* its associated water surface -- use moist unit weight,
2. Soil Unit completely *below* its associated water surface -- use saturated unit weight,
3. Soil Unit *intersected* by a water surface -- the weight of the material above the phreatic surface will be based on the "moist" unit weight while the weight of the material below the intersecting water surface will be calculated according to the "saturated" weight.

The user should note that a piezometric line is NOT the same as a phreatic line. The use of saturated and moist unit weights with a specified piezometric line has been implemented into **XSTABL** for the convenience of the user. For typical cases, the saturation line, corresponding to the phreatic line, will be slightly above the piezometric surface.

F.3 Pore Pressure Calculations

The forces at the base of a slice due to pore water pressures may be simulated in **XSTABL** by employing one of the following methods:

1. ***Phreatic Surface***: This surface, or line in two dimensions, is defined by the free groundwater level. This surface may be delineated, in the field, by using open standpipes as monitoring wells. This is the most commonly programmed method available.

2. ***Piezometric Data***: Specification of pore pressures at discrete points, within the slope, and use of an interpolation scheme to estimate the required pore water pressures at any location. The piezometric pressures may be determined from :

    (1) field piezometers,

    (2) a manually prepared flow net, or

    (3) a numerical solution using finite differences or finite elements.

    Although, this approach is only available in a few slope stability programs, it is the best method for describing the pore water pressure distribution.

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3. ***Pore pressure ratio***: This is a popular and simple method for normalizing pore water pressures measured in a slope according to the definition:

$$r_u = \frac{u}{\sigma_v} \qquad \textbf{(E.1)}$$

where u is the pore pressure and σ_v is the vertical subsurface soil stress at depth z. Effectively, the r_u value is the ratio between the pore pressure and the total vertical stress at the same depth. The normalized data is then available for developing correlations, e.g. see Sherman and Clough, 1968; Leonards and Humphrey, 1984 for a summary of pore pressure data from earth dams during construction.

This factor is easily programmed, but the major difficulty is associated with the assignment of the parameter to different parts of the slope. Often, the slope will require an extensive subdivision into many regions with different r_u values. This method, if used correctly, will permit a search for the most critical surface. However, it is usually reserved for estimating the FOS value from slope stability charts or for assessing the stability of a single surface, as presented in the example problem.

4. ***Piezometric Surface***: This surface is defined for the analysis of a unique, single failure surface. This approach is often used for the back-analysis of failed slopes. Because the combination of a piezometric and a failure surface is unique, a search for the critical surface is not possible. The user should note that a piezometric surface is NOT the same as a phreatic surface, as the calculated pore water pressures will be different for the two cases.

5. ***Constant Pore Water Pressure***: This option is available if the user wishes to specify a constant pore water pressure in any particular soil layer. This may be used to examine the stability of fills placed on soft-soils during construction where excess pore water pressures are generated according to the consolidation theory.

Phreatic Surface

If a phreatic surface is defined, the pore water pressures are calculated for the steady state seepage conditions according to the sketch shown in Fig. F.1. This concept is based on the assumption that *all* equipotential lines are straight and perpendicular to the segment of the phreatic surface passing through the discretized slice.

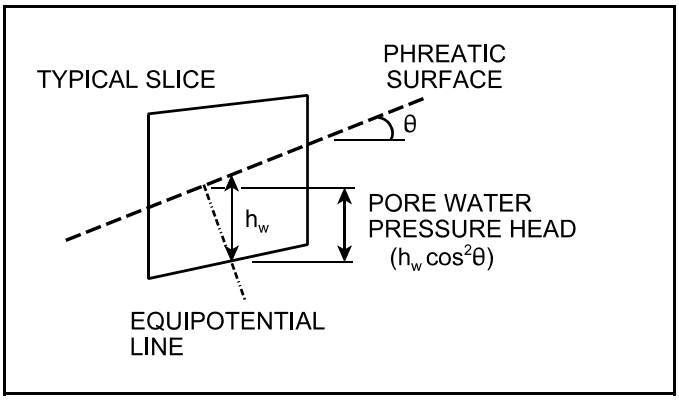

Fig. F-1. Calculation of pore pressure head from phreatic surface

Thus if the inclination of the phreatic surface segment is θ, and the vertical distance between the base of the slice and the phreatic surface is h_w, the pore pressure is given by:

$$u = \gamma_w (h_w \cos^2\theta) \qquad \textbf{(E.2)}$$

where γ_w is the unit weight of water. This is the easiest approach that can be readily programmed and the phreatic surface may be defined with minimal data.

This is a reasonable assumption for a sloping *straight-line* phreatic surface, but will provide ***higher*** or ***lower*** estimates of pore water pressure for a curved (convex) phreatic surface. For the steeply sloping phreatic surface, a convex-shaped phreatic surface (as shown in Fig. F.2) generates an overestimate of the pore water pressures whereas a concave-shaped surface may lead to an underestimation. This feature is shown in Figure F.2. This over estimation is entirely due to the assumption of straight equipotential lines intersecting the projected phreatic surface line, CD. If the actual phreatic surface (line AB) is steeply curved, the equipotential lines must also curve, as shown. In this example, **XSTABL** would use the *greater* pore water pressure head $\mathbf{h_1}$ rather than the true head, $\mathbf{h_2}$. However, this over-estimation is small and will only affect a few slices within the sliding mass. Also, this conservatism is not expected to significantly affect the Factor of Safety.

In cases where the user is concerned about this problem, the pore water pressure grid option may be used to simulate the pore water pressure distribution more accurately.

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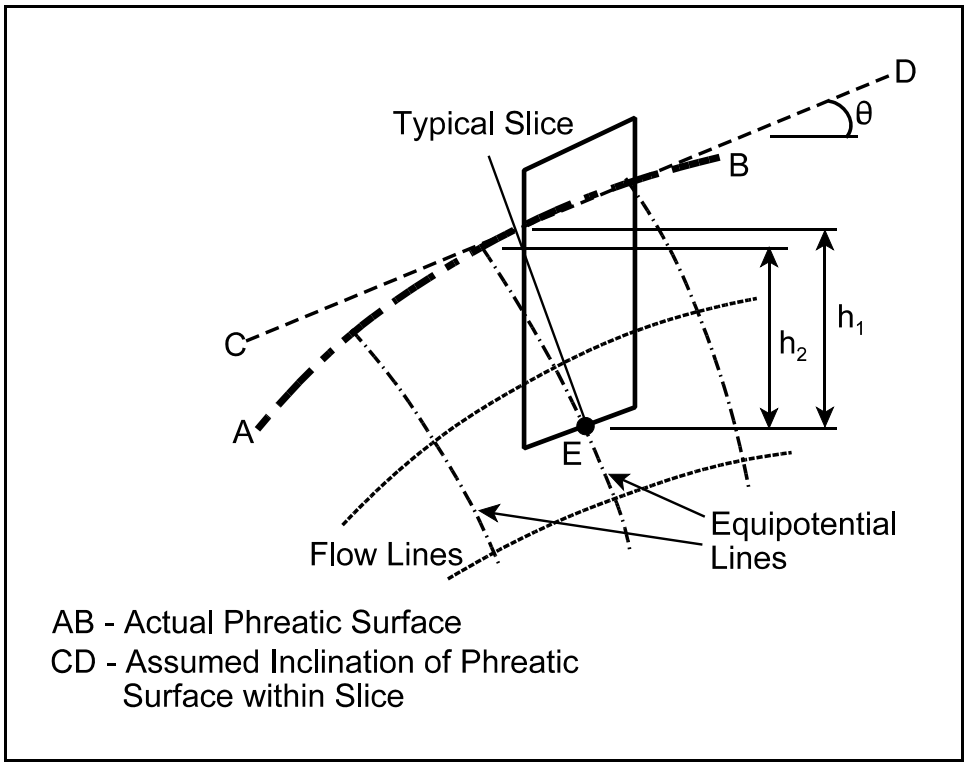

Fig. F-2. Phreatic surface and curved equipotential lines

Piezometric Surface

A piezometric surface may be specified to correspond to a single, ***unique*** failure surface in the slope. This feature is typically used to back-analyze slope failures where the pore water pressures may have been determined from insitu measurements. Fig. F.3 shows the approach taken to calculate the pore water pressure for a piezometric surface.

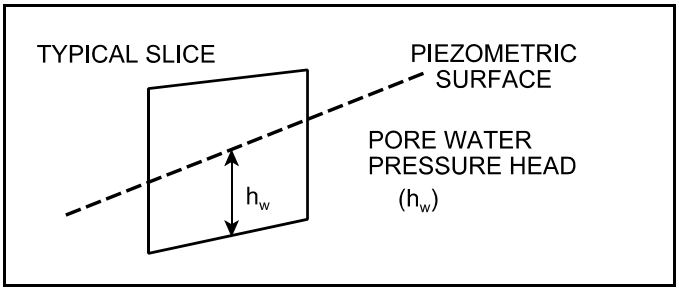

Fig. F-3. Calculation of pore pressure head for piezometric surface

The user should note that the vertical distance (elevational head) is taken to represent the pressure. Also, if a piezometric surface is located above the slope surface, a water surcharge is ***not*** included in the analysis. If the user wishes to include such a surcharge, boundary loads may be specified to simulate these external loads. If a phreatic (water) surface has been specified for the surficial soils, a hydrostatic surcharge is automatically included in the analysis.

There are some computer programs that over simplify the problem by incorrectly assuming the phreatic surface as a piezometric surface. With this erroneous assumption, the over estimated pore water pressure head is incorrectly taken as the vertical distance between the phreatic surface and base of slice, as illustrated in Fig. F.2, rather than the correct approach presented in Fig. F.1.

Pore Pressure Grid

If the pore water pressures are specified at discrete points within a slope, an interpolation scheme is required to estimate the pressures at the required locations. The method proposed by Chugh (1981) provides realistic results and is sufficiently robust to be used within a search procedure for locating the critical failure surface. Other methods based on a weighting scheme may fail to realize consistent results and may, in some circumstances, calculate unrealistic pore pressures.

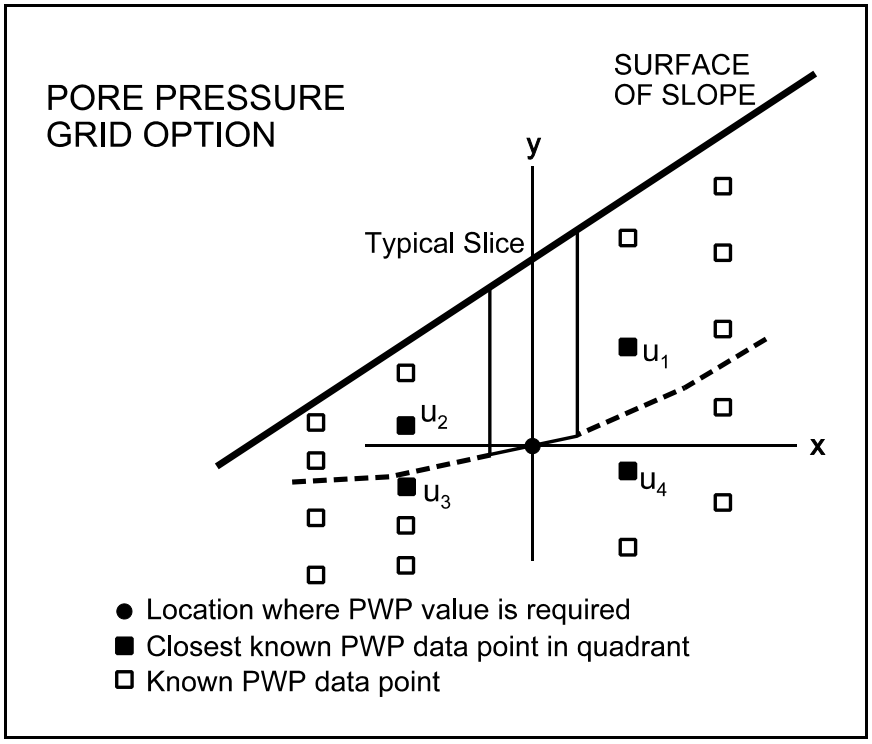

Fig. F-4. Pore water pressure based on interpolation

In Chugh's method, the pore pressures at the required points along the potential failure surface are estimated using an interpolation scheme that uses the "closest" values in each of the surrounding four quadrants. The approach is illustrated in Fig. F.4. The origin, in this figure, represents the location of the point where the pore water pressure is required and which typically would be at the center of the base of each discretized slice. The closest data points in each of the four quadrants (U_1, U_2, U_3, and U_4) are extracted from the input data and the transformed

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coordinate locations: (x_1, y_1), (x_2, y_2), (x_3, y_3) and (x_4, y_4) computed using the center of the slice base as the origin, i.e. $x_i = x - x_c$, where x_i is the transformed coordinate and x and x_c are global coordinates of the known pore water pressure point and base center, respectively.

The interpolation scheme fits a flat surface to three of the known values, and then estimates the pore pressure at the origin (0, 0). The fitted surface is used to estimate the pore pressure and will take the form:

$$U = a_1 + a_2 x_1 + a_3 y_1 \qquad \textbf{(E.3)}$$

The three coefficients, a_1, a_2 and a_3 ,be evaluated for three known points and the pore water pressure at the unknown point (origin) will be equal to a_1. This calculation is repeated four times, each time using a different combination of a set of three known values. The pore pressure value used in the calculations is the average of the four estimated values.

Some similar interpolation schemes may use a *warped* surface, fitted through four known points, to estimate the pore water pressure. This higher order surface takes the form :

$$U = a_1 + a_2 x_1 + a_3 y + a_4 xy \qquad \textbf{(E.4)}$$

where the coefficients, a_1 , a_2 , a_3 and a_4 , may be calculated on the basis of the four known values of pore pressure and their transformed locations relative to the center of the slice base. Unfortunately, this expression does not behave consistently and incorrect pore pressures, either larger or smaller than the surrounding known values, may be calculated with this approach. However, Chugh's method will calculate pore pressure values within the range defined by the surrounding known values: (U_1, U_2, U_3, U_4).

F.4 Submerged Slopes

If part of a slope is submerged, the effect of the surficial water is simulated by a water force acting normal to the inclination of the top of the slice ***only if a water surface is defined as a phreatic surface for the uppermost soil unit within the slice.*** The magnitude of this force is based on the weight of water located directly above the slice in question.

For cases where only a piezometric surface is employed, submerged water forces will have to be implicitly simulated with surface boundary loads. **XSTABL** does not generate such hydrostatic forces for the case where a piezometric line is located *above* the top of the slice. For such conditions, the user can define a thin surface layer, under the submerged water, and then assign a *phreatic* water surface to the soil unit within this layer.

F.5 Earthquake Loads

Once the slices have been discretized according to the slope geometry, the pseudo-static earthquake loads are applied using the specified seismic coefficients. These loads are applied at the centroid of the slice, in the vertical and horizontal directions. The applied loads are a function of the weight of the slice (W) and the seismic coefficients, k_v and k_h, for the vertical and horizontal directions, respectively. The loads are calculated according to:

1. Horizontal Load: $\Delta H = k_h W$
2. Vertical Load: $\Delta V = k_v W$

If a seismic coefficient is specified for calculating a pseudo-static factor of safety, it will not include the inertial effects of the weight of the water above the slice and the direction of the imposed water force on the surface of the slope.

F.6 Boundary Surcharge Loads

The applied surface loads are partitioned directly to the underlying slices. Because the slices are divided according to the geometry of the slope and loads, a search and allocation procedure is used to develop the loads for each slice.

The user should note that in the development of the algorithms in Appendix D, the surcharge load (Q), applied at the surface of the slice, is included in the calculation of the normal stress at the base of the slice. The entire magnitude of the force is transferred from the surface to the failure surface, without any dissipation of the load with increased depth. This external load will directly increase the mobilized shear strength in φ-soils and so the user should be careful in specifying the magnitude of the surcharge load. Fortunately, the analysis is not overly affected by such loads as the greater driving moments/forces are partially offset by the increase in shear resistance.

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REFERENCES

Bishop, A.W. (1955). The Use of the Slip Circle in the Stability Analysis of Slopes, Géotechnique, Vol. 5, No. 1, pp. 7-17, March.

Boutrup, E. (1977). Computerized Slope Stability Analysis for Indiana Highways, Report JHRP-77-25 & 26 (2 Volumes), School of Civil Engineering, Purdue University, West Lafayette, IN 47906.

Ching, R.K.H. and Fredlund, D.G. (1983). Some difficulties associated with the limit equilibrium method of slices, Canadian Geotechnical Journal, Vol. 20, No. 4, pp. 661-672.

Chugh, A.K. (1981). Pore Water Pressure in Natural Slopes, Int. J. of Numerical & Analytical Methods in Geomechanics, Vol. 5, pp. 449-454.

Chugh, A.K. (1986). Variable Interslice Force Inclination in Slope Stability Analysis, Soils and Foundations, Japanese Soc. of SMFE, Vol. 26, No. 1, pp. 115-121.

Fredlund, D.G., Krahn, J. and Pufahl, D.E. (1981). The relationship between Limit Equilibrium Slope Stability Methods, Proc., 10th ICSMFE, Vol. 3, pp. 409-416, Stockholm.

Fredlund, D.G. and Krahn, J. (1977). Comparison of Slope Stability Methods of Analysis, Canadian Geotechnical Journal, Vol. 14, pp. 429-439.

Hynes-Griffin, M.E. and Franklin, A.G. (1984). Rationalizing the Seismic Coefficient Method, USAE, Misc. Paper GL-84-13, Vicksburg, MS.

Janbu, N. (1957). Stability Analysis of Slopes with Dimensionless Parameters, Harvard University, Soil Mechanics Series, No. 46.

Janbu, N. (1973). Slope Stability Computations, in Embankment Dam Engineering, Casagrande Memorial Volume, Hirschfield and Poulos (Eds.), John Wiley, New York, pp. 47-86.

Koerner, R.M. (1991). Geosynthetics in Geotechnical Engineering, Chapter 22 in Foundation Engineering Handbook (H.Y. Fang, Editor), Second Edition, Van Nostrand Reinhold, New York, page 802.

Leonards, G.A. and Humphrey, D. (1984). End of Construction Pore Pressures in Earth Dam Embankments, Report to American Electric Power Services Corp., Ohio.

Lambe, T.W. and Whitman, R.V. (1969). Soil Mechanics, John Wiley and Sons (Pub.), pp. 359-365.

Lovell, C.W., Sharma, S. and Carpenter, J.R. (1984). Slope Stability Analysis with STABL4, Report JHRP-84-19, School of Civil Engineering, Purdue University, West Lafayette, IN 47906.

Morgenstern, N.R. and Price, V.E. (1965). The Analysis of the Stability of General Slip Surfaces, Géotechnique, Vol. 15, No. 1, pp. 79-93, March.

Press, W.H., Flannery, B.P., Teukolsky, S.A. and Vetterling, W.T. (1986). Numerical Recipes, Cambridge University Press, pp. 195-196.

Sharma, S. (1992). Slope Analysis with **XSTABL**, Research Report, Dept. of Civil Engineering, University of Idaho, Moscow, Idaho, U.S.A., 149 pages.

Sharma, S. and Lovell, C.W. (1983). Strengths and Weaknesses of Slope Stability Analyses, Proceedings of the 34th Annual Highway Geology Symposium, Atlanta, pp. 215-232.

Sharma, S. and Moudud, A. (1992). Interactive Slope Analysis Using Spencer's Method, Proc., ASCE Specialty Conference on Stability and Performance of Slopes and Embankments, Berkeley, June 29-July 1.

Sherman, W.C. and Clough, G.W. (1968). Embankment Pore Pressures during Construction, ASCE, JSMFD, Vol. 94, No. SM2, March, pp. 527-553.

Siegel, R.A. (1975). Computer Analysis of General Slope Stability Problems, Report JHRP-75-8, School of Civil Engineering, Purdue University, West Lafayette, IN 47906.

Siegel, R.A. (1975). STABL User Manual, Report JHRP-75-9, School of Civil Engineering, Purdue University, West Lafayette, IN 47906.

Siegel, R.A., Kovacs, W.D. and Lovell, C.W. (1980). Random Surface Generation in Stability Analysis, ASCE, VOL. 107, GT-7, pp. 996-1002, July.

Spencer, E. (1973). The Thrust Line Criterion in Embankment Stability Analysis, Géotechnique, Vol. 23, No. 1, pp. 85-100, March.

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